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JUN 80   A P ALLAN, G D TRANSMEIER
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Due to recent needs expressed by the Air Force, a review and evaluation of the methods of analysis for passive solar energy systems was conducted. The methods of analysis evaluated were those that could be worked without the use of computers or programmable calculators. A selection model was designed to systematically and objectively evaluate the methods. The selection model was a variation of a scoring model and based on six criteria. The criteria were: Performance, Economics, Flexibility, Implementation, Usability, and Computing Devices. Of the methods evaluated, the Passive Solar Design Handbook was the recommended method of analysis to be used in the Air Force. The method was written by the Los Alamos Scientific Laboratory for the Department of Energy. This method was comprehensive yet simple to use and understand.

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A REVIEW OF THE METHODS FOR PASSIVE SOLAR SYSTEMS ANALYSIS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Facilities Management

By

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June 1980

This thesis, written by

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and

Second Lieutenant Gary D. Transmeier

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN FACILITIES MANAGEMENT

DATE: 9 June 1980

COMMITTEE CHAIRMAN

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Chapter 1

INTRODUCTION

Background

Since the early 1970's, the rising price and dwindling supply of fuel has been one of the major concerns of the industrialized world. Although the United States has kept price increases at a minimum with government regulation, it has become more and more apparent that prices will continue to rise and supplies will continue to decrease. This situation has caused a renewed and growing interest in alternative methods of providing the energy that fossil fuels now do. Some of the general areas in which work is being done include nuclear energy, geothermal energy, solar energy, wind energy, and synthetic fuels. The rising costs of fossil fuels have made an increase in research and development of these alternatives practical from an economic standpoint.

Rising costs of fossil fuels also effect the Air Force. The cost of heating and cooling buildings has been a great concern to the Air Force. One of the more promising alternative methods of providing building heating and cooling is solar energy.

On 26 September 1979, the United States Air Force Facility Energy Working Panel: Solar, Wind, and Geothermal met at Headquarters, Air Force Logistics Command at Wright-Patterson Air Force Base to address specific questions and areas of interest to the Air Force within the solar energy area. During this meeting, a recommendation was presented by the panel that outlined the priorities of the Air Force in its efforts to conserve energy (18:3).

The highest priority item stated by the panel was that of facility energy conservation, which requires a small investment of money. This includes increased insulation of buildings, lowering of thermostats, weatherstripping, storm windows and doors, and other methods available today.

The second priority item given by the USAF Facility Energy Working Panel was to pursue cost effective passive solar energy systems (18:3).

The third priority suggested by the panel was the use of active solar energy systems in Air Force facilities. In this case, the rising cost of fossil fuels has contributed to the economic feasibility.

The USAF Facility Energy Working Panel: Solar, Wind and Geothermal concluded its meeting with the view that "passive features should be emphasized in the fiscal year 1982 and future Design Instruction/Design Consideration (18:4)." The panel also recommended that Headquarters Air Force Engineering and Services Center "investigate the most

appropriate passive computing methods to be used Air Force wide [18:4]." The last recommendation was that "the Air Force Institute of Technology School of Civil Engineering add to their professional continuing education program the topic 'Passive Analysis Techniques' [18:4]." As of January, 1980, the Air Force Engineering and Services Center has not investigated any passive computing methods to be used in the Air Force.

The Air Force Facility Energy Plan stated that the Air Force goal is to receive 1% of its facility energy demands from solar energy and geothermal energy by 1985. The plan further requires the use of alternative energy resources whenever economically feasible (1:8). In a 1979 presidential address, a goal of 10% of facility energy demands fulfilled by solar energy by the year 2000 was proposed by President Carter. Passive solar energy systems will play an important part in meeting these goals proposed by the President and the Air Force.

Passive solar energy systems are just one form of direct solar energy systems (see Figure 1). Direct solar energy systems directly convert solar radiation into a readily usable form of energy. Direct solar energy systems can be separated into electrical, thermal, and chemical. Electrical solar energy systems directly convert solar radiation into electricity. Photovoltaic cells are an example of electrical solar energy systems. In chemical

solar energy systems, solar radiation causes a chemical reaction with the end result being a chemical compound with a high energy storage capacity. Photosynthesis is an example of a chemical solar energy system. Thermal solar energy systems involve converting solar radiation into heat.

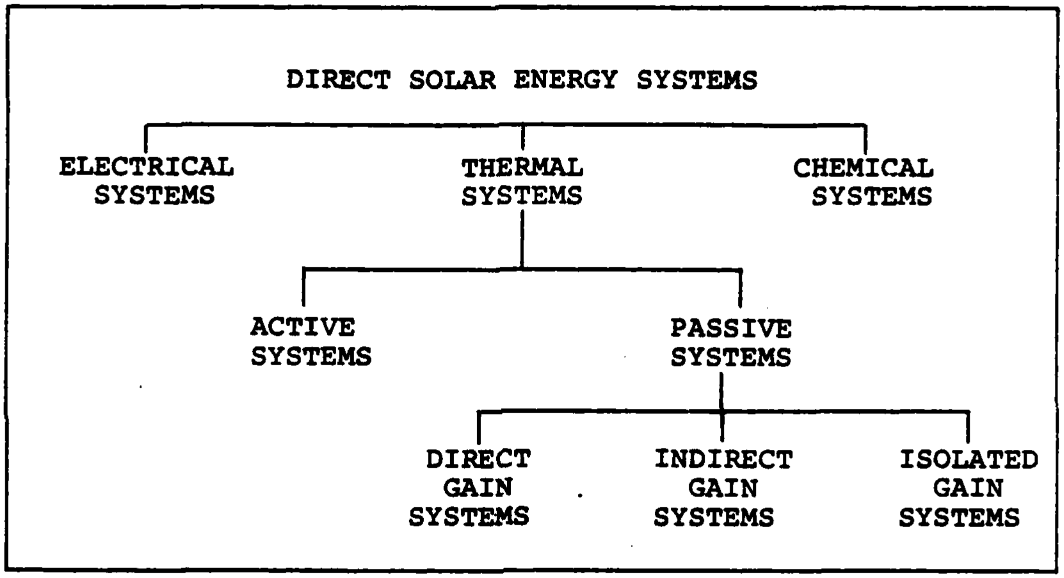

Figure 1

Direct Solar Energy Systems

A passive solar system was defined by the National Bureau of Standards in this manner:

> A passive solar heating system is an assembly of collectors, thermal storage device(s) and transfer media which converts solar energy into thermal energy and in which no energy in addition to solar is used to accomplish the transfer of thermal energy. The prime element in a passive solar system is usually some form of thermal capacitance. When the passive heating systems now in use are examined, it is found that the prime element is generally the means by which solar energy is admitted to the structure rather than the storage means [6:429].

The Department of Housing and Urban Development defined a passive system in this way:

> A 'Passive' solar energy system is one which uses the building structure as a collector, storage and transfer mechanism with a minimum amount of mechanical equipment. This comes closer to expressing the passive concept but it would exclude the oldest and most widely used solar heating device, the thermosyphon water heater in which the collector is generally <u>not</u> a part of the structure [7:429].

Finally, the Conference on Passive Systems under the direction of the Energy Research and Development Administration and the Los Alamos Scientific Laboratory devised their own definition of a passive solar energy system:

> Passive systems use the sun's radiation for heating and nocturnal processes for cooling; heat distribution is accomplished by convection, radiation and conduction. Non-renewable energy used for movement of insulation, diurnal transfer of water from one space to another, movement of dampers or valves, etc., must be so small in amount that the 'Coefficient of Performance' of the system, defined as the ratio of the useful heating or cooling accomplished by renewable energy sources or sinks to the non-renewable energy consumed, is greater than 50 to 1. This definition is consistent with the intent of the Solar Heating and Cooling Act of 1974, which includes the processes of radiation, convection and evaporation in its definition of solar cooling. When both heating and cooling can be accomplished with negligible consumption of non-renewable energy, then the system may indeed be called "passive" [7:429].

There are a variety of passive solar energy systems. To add to the above definitions, this area will be divided into three generic types. The three types of passive systems are direct gain, indirect gain, and isolated gain.

Direct gain is the most basic type of passive system. Solar radiation penetrates a south-facing glazing (a glass

or plastic transparent material) and strikes interior walls and floor. The walls and floor absorb the radiation, thus serving as the storage mass for the system. The energy is released from the mass when the indoor air temperature falls below the storage mass temperature. Because of the high density of the mass, this energy is released slowly, usually throughout the night after a clear sunny day. The space between the glazing and the storage mass wall is large enough to serve as a functional room of the building. Figure 2 shows an example of this system.

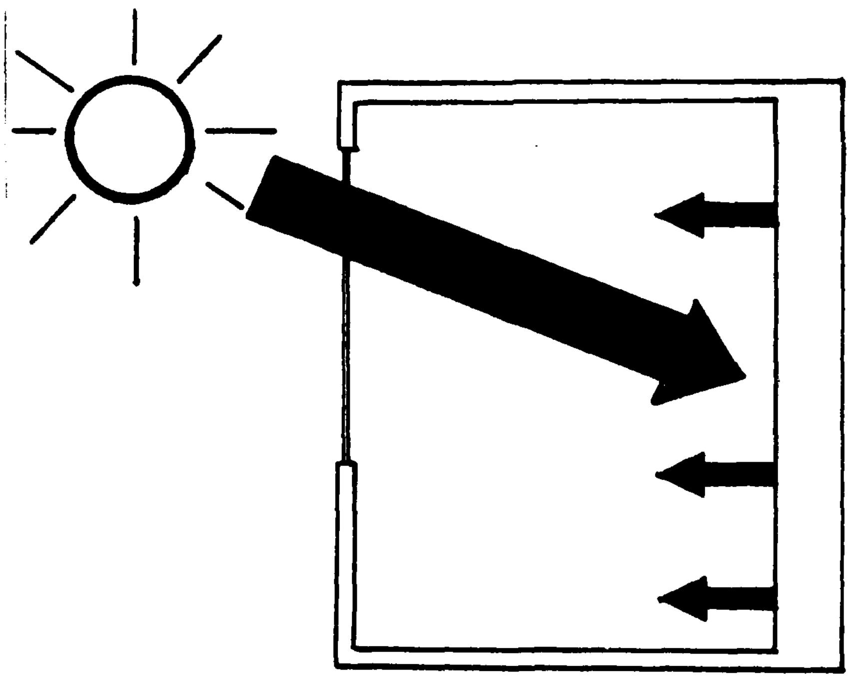

Figure 2

An Example of A Direct Gain Passive Solar Energy System

The indirect gain system is a modification of the direct gain concept. The storage mass wall is within a few inches of the glazing. The storage mass absorbs the incoming radiation on the glazing side and reradiates or conducts energy out the other side if the air temperature is below the wall temperature. In addition to this heat transfer, vents can be in the upper and lower portion of the wall. Cooler air from the other side of the wall flows into the bottom vents and rises between the glazing and storage mass wall. As it rises, the incoming solar radiation heats the air. The air flows out the top vents. This natural circulation is driven by the temperature difference between the space in between the glazing and storage wall and the room on the other side of the storage wall. Figure 3 shows an example of the above system, the Trombe wall, named after Felix Trombe, who worked with Jacque Michal to build the passive system.

The third type of passive solar energy system is the isolated gain system. This type of system is attached to the outside of the building. The energy from the system is transferred into the building by conduction through a wall or ceiling or natural convection through vents in the wall. An example of this type of system is the roof pond shown in Figure 4A. Water in plastic bags serve as the storage mass for the system. In the winter, the solar radiation is absorbed and stored by the water and reradiated

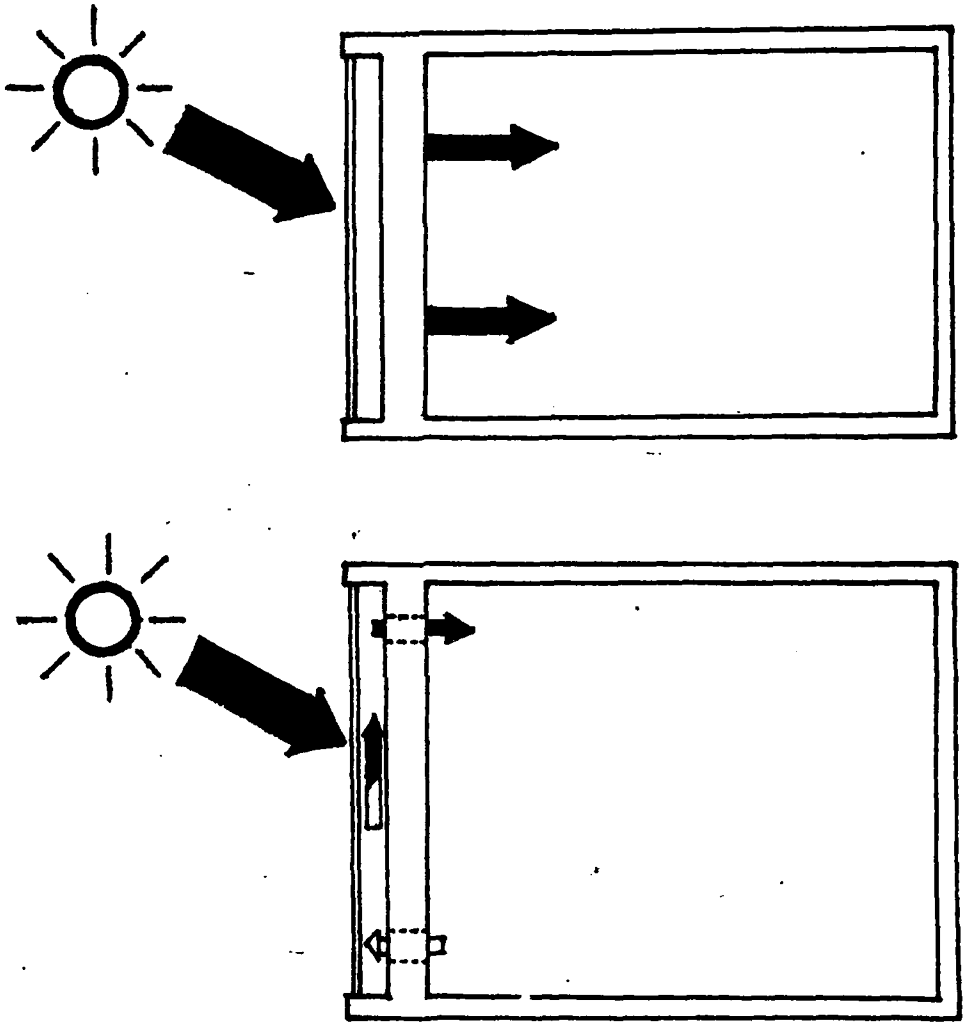

Figure 3

An Example of An Indirect Gain Passive
Solar Energy System

to the rooms below. At night the pond is covered with insulation to reduce energy loss to the atmosphere. In the summer, the roof pond is covered by the insulation during the day. The water absorbs and stores the indoor energy and releases the energy to the atmosphere at night when the insulation is removed.

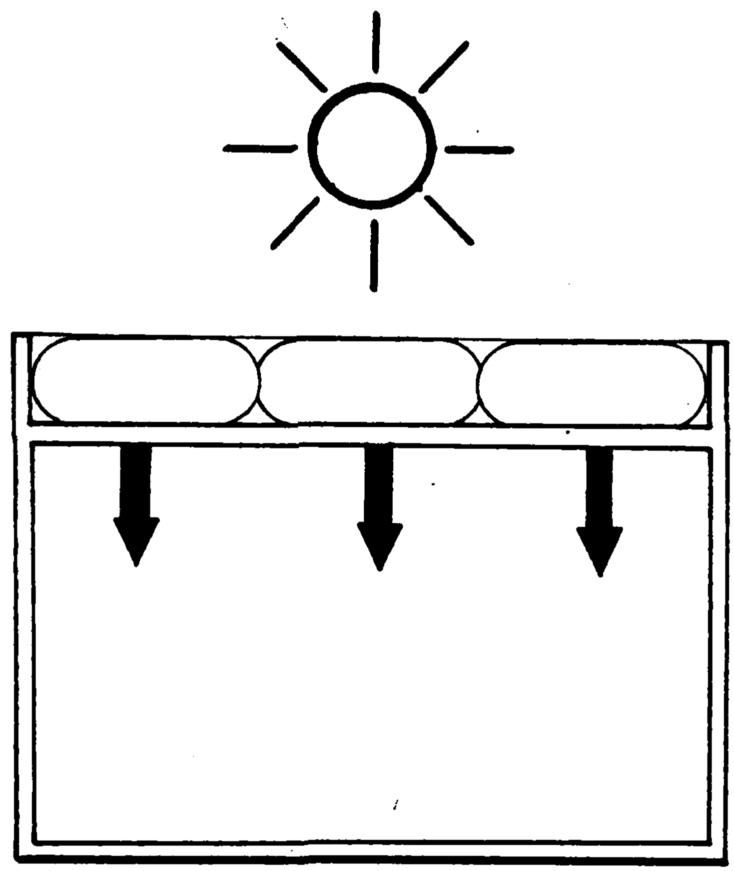

Figure 4A

The Roof Pond

Another example is the attached greenhouse. The solar energy available at the glazing is sufficient not only for the greenhouse but can also aid in heating the building. The means of transfer of energy from the greenhouse to the building can be either by conduction or natural convection. The greenhouse has the added advantages of having a garden and serving as a buffer to cold temperatures and high winds. Figure 4B shows a diagram of a greenhouse.

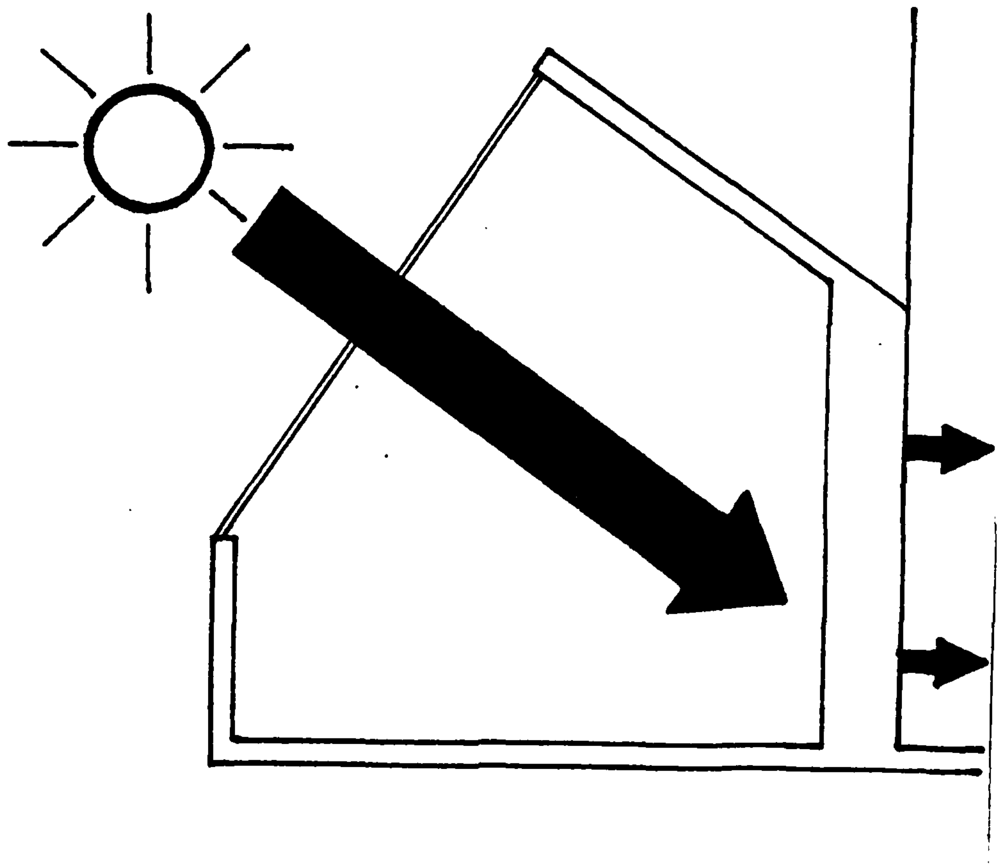

Figure 4B

The Attached Greenhouse

Objectives

Methods of analysis can vary greatly. Ron Judkoff of the Solar Energy Research Institute divides these methods into four levels (9:290):

1. Simulation programs requiring large computers.

2. Simulation programs adapted for micro-computer systems.

3. Hand-held programmable calculator methods.

4. Hand methods.

This thesis will concentrate on the fourth level--hand methods. They are the most applicable to the user since they only require a pencil and paper. A technique which can also be used on a computer will be looked to as an important advantage.

The objectives of this thesis are as follows:

1. To design a selection model based on a set of criteria consistent with the needs of the Air Force.

2. To use this selection model to compare existing analysis methods for passive solar systems design.

3. To recommend an analysis technique for passive solar systems design for use by the Air Force.

This thesis will thus address the immediate needs of the Air Force by recommending an analysis technique for passive solar energy, and will be used to assist the Air Force in the future by presenting a selection model upon which to measure new analysis methods.

Method of Analysis

The method of analysis will consist of a procedure in which the user enters input data, operates the method, and extracts output data. Along with the procedures, instructions will be included in the package which explain each step. The term "package" will be used to mean the method of analysis and all its components.

The User

This chapter will answer three questions concerning the user of the package. Who is the user? What can the user expect from the package? What does the user need to know in addition to the package?

Who is the user? The user is anyone involved in the design of a facility. The design can be for a new facility or a retrofit project to increase the energy efficiency of an existing building. It is not suggested here that passive solar energy systems are suitable for all facilities. However, passive solar energy systems should be seriously considered wherever economically feasible.

What can the user expect from the packages? The user should be able to expect the package to provide all the necessary performance and economic information. All the information required by the Air Force pertaining to the proposed passive solar energy system should be generated by the package.

What does the user need to know in addition to the package?

The user needs knowledge of the passive solar energy area. Information equivalent to that which is taught in the Contemporary Energy Applications class at the Air Force Institute of Technology's (AFIT) School of Civil Engineering is essential.[1] Knowledge of construction and architecture is recommended.

[1]This class is not planning to teach a passive solar energy package until FY 81.

Chapter 2

THE SELECTION MODEL

The selection model proposed in this chapter will be used as a basis for recommending the best method for passive solar energy system analysis. The purpose of this model is to present an objective, systematic process for evaluating the methods for passive solar energy system analysis that is easy to understand. The model selected for this thesis is a variation of a scoring model. A scoring model is simple to use and understand (4:90). In order to evaluate the methods, several criteria are required (discussed later in this chapter); therefore, the model must handle multiple criteria. The scoring model is based upon using multiple criteria (4:76).

The Criteria

There are six criteria in the selection model. They are labeled Performance, Economics, Flexibility, Usability, Implementation, and Computing Device. Each criterion is further subdivided into two criterion characteristics. The criterion will be described next.

Performance. The package should calculate information about the performance of the passive solar energy system with

respect to the building. One of the two criterion characteristics is the fractional contribution of the passive solar energy system to the heating requirements of the building. The heating requirements of the building are based upon the heat loss by conduction through the exterior surfaces and infiltration through cracks in those surfaces minus the heat from appliances and people. The fractional contribution of the passive system for this characteristic is the annual or yearly fraction. It is based upon the average monthly fraction.

The second criterion characteristic is the average daily indoor temperature fluctuation. This value is based upon the average monthly temperature in January. The temperature fluctuation is of major concern because the indoor temperature can rise above a comfortable range or drop below this range. If the temperature rises too high, the excess heat has to be vented out of the building, resulting in a waste of energy. If the temperature drops below a comfortable range, the difference must be compensated by auxiliary heating.

Economics. The package should contain the economic information necessary to analyze the economic feasibility of the passive solar energy system. Several economic figures exist which describe the economics of the system. The two used in this criterion are those required for submitting a project

to the Energy Conservation Investment Program (ECIP). The two criterion characteristics are Discounted Benefit/Cost (B/C) Ratio and the MBTU Saved/$1000 Current Working Estimate Invested (E/C) Ration (1:B-1-1). MBTU Saves is the Million British Thermal Units saved per year by the passive solar energy system. The calculation of both these values are explained in Appendix B-3 of the Air Force Facility Energy Plan and DOD 7041.3, Economic Analysis and Program Evaluation for Resource Management (1:B-3-2). Other economic parameters will be easily obtained from worksheets that calculate B/C and E/C ratios. For example, pay-back period could be derived from the total cost and annual dollar savings, both of which are used to calculate the B/C ratio (1:B-3-4).

Flexibility. The package should handle the two major types of passive solar energy systems; direct and indirect gain. There are other systems, such as the isolated gain system, but they represent a small amount of the systems that will likely be used in Air Force facilities. Chapter 1 discussed the various types of systems.

Usability. This criterion deals with the time and ease to run the procedure. The first criterion characteristic is the time it takes the user to run through the procedure. Once the user is familiar with the package, the procedure should not take more than three hours to complete.

Initially, the user may need more time to grasp the procedure. For purposes of this thesis, the 3 hour average time for the user familiar with the procedure to run the procedure will be used.

The second criterion characteristic is that the procedure should be simple to use. The procedure should consist of worksheets with rows and columns which are added, subtracted, multiplied, or divided. The user should need only a pencil and a hand-held calculator or slide rule. Data for the worksheet should be extracted from graphs, tables, or the design. This condition will be considered a simple procedure. A more complex procedure would require the use of the Calculus.

<u>Implementation</u>. Implementation deals with getting the package to the user. The first criterion characteristic is that all the necessary information should be in the package. The package should consist of a user's manual with instructions, examples, assumptions, and limitations of the procedure. The procedure should have all the necessary graphs, tables, or equations.

The second criterion characteristic is that the package should be inexpensive. Packages that have been published or available in such quantities that their cost per copy is under $10 will be considered inexpensive. Packages in which a purchase of a copyright or a percent in

royalties would have to be paid by the Air Force or the user will be considered expensive.

Computing device. All the criteria except for this one will be judged on the hand-worked procedure only. Computers have the capability to greatly reduce the procedure time and make the operation of the package easier. However, the writing of the computer program can be costly. Therefore, if the package had an equivalent form for a computer, then the computer version would be very advantageous to the user. The first criterion characteristic is that the package has a version available for a computer. The procedure of the computer version would be more advantageous if it was interactive with the user. In an interactive system, the computer program asks direct questions, and the user gives the computer the information it needs. Results are then given back to the user based on that information. The second criterion characteristic deals with the interactive ability of the computer program.

Table 1 is the selection model scoring sheet. It lists the six criteria and 12 criterion characteristics.

The Scoring Procedure

The scoring procedure is how each package will be evaluated in the selection model. Table 2 summarizes the scoring procedure.

Table 1

Selection Model Scoring Sheet

Name of Method	(1) Raw Rating	(2) Criteria Score (AxB)	(3) Weight Factor	(4) Weighted Score (2)x(3)
1. Performance:		___	.178	___
A. Provide yearly fractional load	___			
B. Provide average daily indoor temperature fluctuation	___			
2. Economics:		___	.178	___
A. Provide B/C Ratio	___			
B. Provide E/C Ratio	___			
3. Flexibility:		___	.169	___
A. Handle direct gain systems	___			
B. Handle indirect gain systems	___			
4. Usability		___	.164	___
A. Take little time	___			
B. Simple procedure	___			
5. Implementation:		___	.160	___
A. All information in package	___			
B. Inexpensive	___			
6. Computing device:		___	.151	___
A. Computer version available	___			
B. Package is interactive	___			

INDEX NUMBER[Σ(4)] = ________

Table 2

Scoring Procedure

I. Give following — if

Give following	if
4	wholly contained in package.
3	not contained in package, but easily & inexpensively modified.*
2	not contained in package, costly or difficultly modified.
1	not contained in package, not modifiable.

to each criterion characteristic (12 in all).

*Modification by the user or the Air Force.

II. Multiply the A & B raw score of each criterion to obtain the criteria score.

III. Multiply the weight factor by the criteria score to obtain the weighted score (Col. 2 x Col. 3).

IV. Add the six weighted scores together to obtain the index.

V. The above procedure is repeated for every package.

VI. The package with the highest index will be the recommended "best" package.

Rating system. Each criterion characteristic is given a rating based on a one to four scale. This rating will be called the raw rating. The rating will be assessed in the following manner.

A "4" will be given if that criterion characteristic is completely contained in the package. A "3" will be given if the criterion characteristic is not wholly contained in the package but could be easily and inexpensively modified by the user or the Air Force. A possible example of this type rating would be if a table from the ASHRAE "Handbook of Fundamentals" is needed. The table could be obtained easily and inexpensively by the user or the Air Force.

A "2" will be given if the criterion characteristic is not wholly contained in the package and modification to the package would be costly or difficult. A possible example of this rating would be if the Air Force would contract out or write a complex computer program. The computer program is possible to obtain but at high cost. A "1" will be given if the criterion characteristic is not contained in the package and it would be impossible to modify. An example of this rating would be if the copyright owner of the package would not allow a computer program be written using his procedure until he wrote the program himself.

This rating system is directly applicable to the criterion characteristics except for a few. The following decision rules will help apply the rating system. For

criterion characteristic 4A (see Table 1), a "4" will be given if the 3 hour time span can be achieved. A "3" will be given if it takes between 3 and 5 hours. If the time is from 5 to 8 hours to complete one run, a "2" will be given. A "1" will be given if the procedure takes more than 8 hours to complete.

For 4B, a "4" will be given if graphs and tables are adequate. A "3" will be given if graphs and tables can be easily made. If it should be costly to make the necessary graphs or tables, a "2" will be given. A "1" will be given if the graphs or tables are impossible to make.

For 5A, if the package has equations instead of graphs or tables, there will be no penalty assessed. However, if some equations are not in the package and there are no graphs or tables with the data, then the rating scheme will be applied accordingly. Whether the data will be from equations or graphs will be assessed in 4B.

For 5B, a "4" will be given if the package should cost under $10 per copy. A "3" will be given if the package should cost between $10 and $50 per copy. For a package that should cost between $50 and $100 per copy, a "2" will be given. A "1" will be given if the package costs over $100 per copy or if a fee will have to be paid on every run of the procedure. The cost per copy will be assessed at current prices.

No decimal values will be given for the raw rating. If the package being evaluated should have a characteristic in between the rating, the authors of this thesis will use their best judgment of which rating to assign.

Calculating the index. The raw rating of each criterion characteristic within each criterion will be multiplied together. This product will be called the criteria score. There will be six criteria scores, each between one and 16. Each criteria score will be multiplied by its appropriate weight factor (see Table 2). Then all the criteria scores are added together to yield an index number called the index. This scoring procedure will be repeated for every package being evaluated. The package with the highest index will be the recommended "best" package. If the package should not receive a perfect 16.000 index, then a discussion of the necessary modifications will accompany the recommendation. If a tie should occur for the highest index, the packages will be subjectively compared for small differences and both recommended. Ties that occur for lower indexes will be considered irrelevant.

Determination of the weight factors. The weighting factors were determined by rank ordering the six criteria. Then an arbitrary value of 2.0 was assigned to both performance and economics. Both criteria are believed to be of primary importance in evaluating the system. The other criteria

were assigned decreasing values. The decrease was kept small to prevent dominance of any one or group of criteria. Table 3 lists the raw weights and criteria in the ranked order.

The weights were normalized by dividing each raw weight by the sum of the raw weights. There were two advantages for the weighting scheme. One was to put the index on the same scale as the criterion score, and the other was to minimize the chance for a tie.

Table 3

Selection Model Weighting Scheme

Criteria	Raw Weight	Normalized Weight
Performance	2.00	.178
Economics	2.00	.178
Flexibility	1.90	.169
Usability	1.85	.164
Implementation	1.80	.160
Computing Device	1.70	.151
SUM	11.25	1.000

Chapter 3

EVALUATION OF THE PACKAGES

INTRODUCTION

This chapter contains the evaluation of the seven methods (each evaluation comprises a separate section). The seven methods for passive solar systems analysis are:

1. the Solar Load Ratio method,
2. the Resistance Network Design method,
3. the Rules of Thumb "Patterns" method,
4. the Trombe Wall Load Analysis method,
5. the Lawrence Berkeley Laboratory Modeling method,
6. the Lumsdaine Simple Design method, and
7. the Passive Solar Design Handbook method.

Each section will include an introduction (describing the program and the authors of the program) followed by the specific evaluation procedure. The procedure was based on the selection model derived in the second chapter. The evaluation procedure is divided into two parts. In the first part, each criterion characteristic is reviewed based on its importance to the particular method being reviewed. Justification for the raw scores are presented. The second part of the evaluation process presents the selection model scoring sheet. The scoring sheet shows the raw rating,

criteria score, weighted score, and index number for the respective method.

SOLAR LOAD RATIO METHOD

The Solar Load Ratio (SLR) method was originated by J. Douglas Balcomb at the Los Alamos Scientific Laboratory in Los Alamos, New Mexico. The equations and graphs were incorporated into a tabular methodology by Fuller Moore at Miami University, Oxford, Ohio.

The package evaluated in this thesis consists of three parts. The major part is the package by F. Moore. This part contains an article by J. D. Balcomb and R. D. McFarland entitled, A Simple Empirical Method for Estimating the Performance of a Passive Solar Heating Building of the Thermal Storage Wall Type (15). The worksheets and two examples are also included.

The second part is an article by W. O. Wray, J. D. Balcomb, and R. D. McFarland entitled, A Semi-empirical Method for Estimating the Performance of Direct Gain Passive Solar Heating Buildings (19). This article was included because it deals with direct gain systems in the same fashion as the article in the first part, which deals with thermal storage systems. The calculations and results presented by W. O. Wray have been incorporated by F. Moore in the first part.

The third part is an article by J. Douglas Balcomb entitled, Performance Simulation and Prediction (2). This article gives an overview of how this type of method should be used and the role of this type of methodology in the design phase of a passive solar system.

The SLR method is semi-empirical. An average condition was assumed and a reference system defined. A computer simulation was conducted on that reference system. Equations and graphs were derived from the generated data. Table 4 is the reference system used in the SLR method.

The primary correlation is the monthly solar heating fraction (SHF) as a function of the solar load ratio (SLR). Six different systems were analyzed by computer to obtain a graph of the relationship for each system. A least-square fit was made to the data for each system type. One curve exists for each of the following: water wall, with and without night insulation; Trombe wall, with and without insulation; and direct gain, with and without night insulation. Equations for the curves have also been derived. The curves follow a linear function till SLR of about 0.8 (the trade-off point varies between curves) then the curves increase following a negative exponential function (see Figure 5).

The solar load ratio consists of the numerator dealing with the solar energy absorbed and the building thermal load in the denominator. Graphs of the Vertical/ Horizontal Factor and Reflector Enhancement Factor as a

Table 4

Reference Passive Solar Systems Used for Correlations

DIRECT GAIN

Thermal Storage = 45 BTU/°F ft^2 of glazing
Trombe wall has vents with backdraft dampers
Double Glazing (normal transmittance = 0.747)
Temperature Range in Building: 65°F to 75°F
Building Mass is Negligible
Night Insulation (when used) is R9;
5:00 p.m. to 8:00 a.m.
Wall to room conductance = 1.0 BTU/hr °F ft^2
Trombe wall properties k = 1.0 BTU/ft hr °F
pc = 30 BTU/ft^3 °F

INDIRECT GAIN

Thermal Storage = 45 BTU/°F ft^2 of glazing
Mass Distribution = 6 in. thick layer of concrete on floor and north, east or west walls. Mass surface area is three times the glazing area.
Other Building Mass = Negligible
Double Glazing = Normal solar transmittance = 0.747
Air Temperature Range in Building = 65°F to 75°F
Night Insulation = R9 when used. Insulation in place from 5:00 p.m. to 7:00 a.m.
Mass-surface-to-room air conductance:
1.0 BTU/hr ft^2 °F
Storage Mass Properties:
thermal conductivity = 1.0 BTU/hr ft °F
heat capacity = 30 BTU/ft^3 °F
Glazing Orientation = Vertical and south facing
Mass Surface Solar Absorptance = 0.8
Ground Reflectance = 0.3
Overhang = None

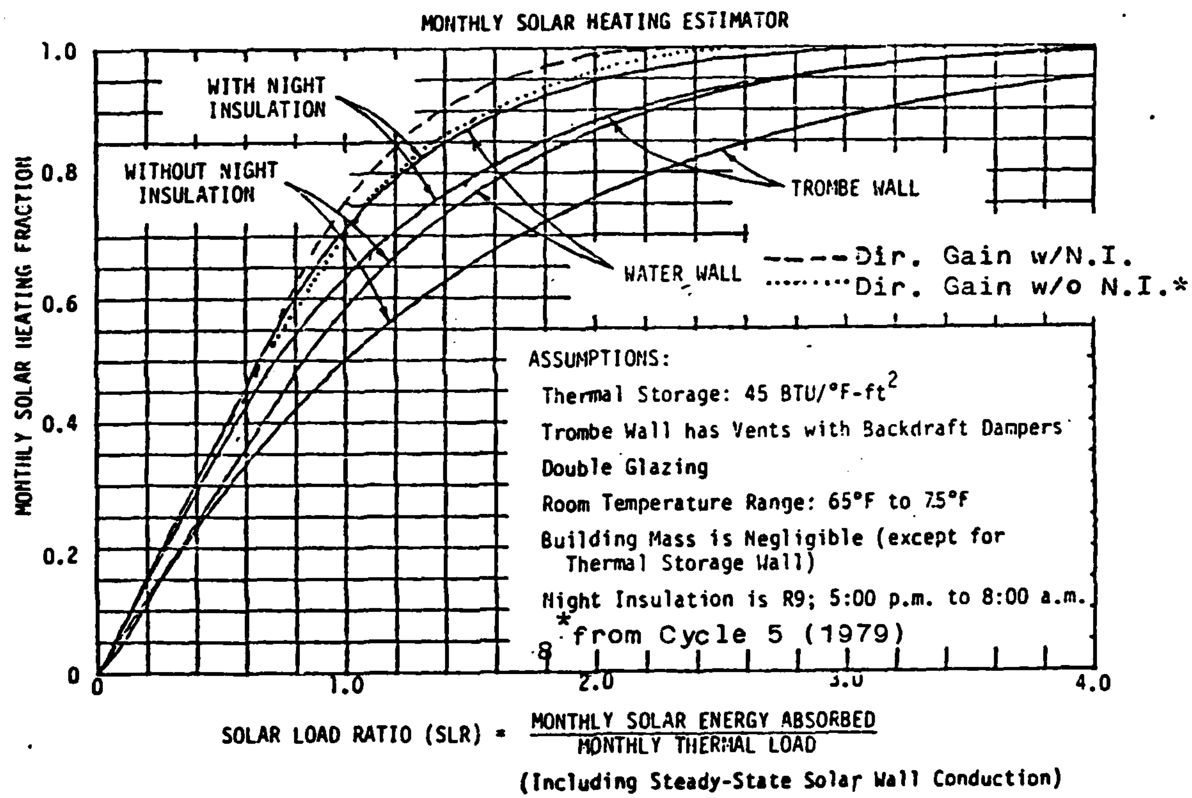

Figure 5

Monthly Solar Heating Estimator

function of the L-D (latitude minus solar declination) were developed from the empirical data (15:12).

The package has two worksheets. The first calculates the unmodified and modified Building Load Coefficient[2] (BLC) along with the internal heat generation (15:16). The second worksheet computes the monthly SHF and the auxiliary heating requirement (15:17).

Evaluation

Performance. The SLR method computes the SHF and the auxiliary heating requirement on an average monthly basis. The annual SHF is obtained by summing the auxiliary heat required and Degree Days (DD) for each month. Then the following equation is used to obtain the annual SHF:

$$SHF_{annual} = 1 - \frac{(\text{annual aux heating})(10)^6}{(BLC_{unmod})(DD_{annual})} \qquad (15:5)$$

This method is completely consistent with the first criterion characteristic. Therefore, the SLR method received a "4" for this criterion characteristic.

The SLR method is based upon an indoor design temperature of 65°F. By using this temperature, there is a

[2]Modified BLC includes the solar wall, while it is not included in the unmodified BLC.

large increment for the temperature to rise to an uncomfortable level. Due to this increment, the detailed calculations needed to provide the predicted temperature fluctuations were not considered in this method. Temperature deviations below the design temperature are reflected in the auxiliary heating requirements. The calculations to obtain temperature fluctuations involve hour-by-hour simulations, a difficult feat for hand methods. Since the SLR package does not provide temperature fluctuation predictions, and this information would be difficult to generate, the SLR method received a "2" for the corresponding criterion characteristic.

Economics. The SLR method provides an equation that will calculate the life-cycle savings of the passive solar heating system (15:20). The savings calculated are those only for the decreased use of fuel in the auxiliary heating system over the alternative of no passive solar heating system. The equation takes into consideration the time-value of money and the inflation of fuel prices. The equation does not derive the investment costs of the passive system. The total cost of the passive system has to be calculated through other means. The E/C and B/C ratios can be calculated from the variables in the economic analysis equation. However, these relationships are not defined. Because the SLR method does not derive the E/C and B/C ratios, but can

be easily modified to do so, it received a "3" for both the criterion characteristics.

Flexibility. Originally, the SLR method was designed for the Trombe wall and the water wall, both indirect gain systems. The current SLR package can be used for both direct and indirect gain systems. The SLR method was based on fixed data for an average system design. Some accuracy is sacrificed as the proposed design differs from the SLR reference design. F. Moore included correction factor graphs to improve the accuracy (15:15), but some accuracy is still lost, especially in more exotic designs. Both characteristics of the "flexibility" criterion received a "4".

Usability. The SLR method takes relatively little time to work through the worksheets. It took one of the authors of this thesis one hour to work through the worksheets for the example given in the package. More time may be needed to obtain the input data. Time can be saved by having the DD and solar energy information already entered on the worksheets. Additional time can be saved if the building load is known from previous work. Iterations to check the sensitivity of the parameters can be achieved in much less time than it takes to work through the whole procedure (the exact time will depend upon the variable being changed). The "takes little time" criterion characteristic received a "4", according to the scale in Chapter 2.

The SLR procedure is simple. Only multiplication and addition are needed to work through the worksheets. The equation that relates SLR to the SHF involves an exponential, but a figure is also given with the same information, making the use of the equation optional. The economic equation involves variables taken to the power of other variables. The simplicity of the equation can not be increased, but tables can be used to provide the capital recovery factor (CRF) and fuel inflation factor. The tables are not provided by the package. The SLR method received a "4" for the "simple procedure" criterion characteristic.

Implementation. Everything is not in the package. Some of the necessary information has to be obtained elsewhere. The monthly DD and the horizontal solar radiation have to be extracted from weather data not included in the SLR package. Also, the U-values for the walls have to be obtained from some other source. The criterion characteristic, "All information in package", received a "3" because of the above omissions. However, the additional information would be easy to obtain and incorporate into the package.

The package is relatively small. The package evaluated in this thesis was 37 pages long, including sample worksheets and two examples. The package should be inexpensive to procure. Therefore, it received a "4" for the "inexpensive" criterion characteristic. The package should

easily fall into the "4" price category as explained in Chapter 2.

Computing device. A computer program developed from this SLR package does not exist. There is a program for the Texas Instrument, TI-59, calculator for the method, but this program is not addressed in this thesis (see Computing Devices in Chapter 2). If it were desired to have a computer program for this method, it could be made fairly easily. However, computer programs require a large amount of time to write and become operable. Making the program interactive would require only a little additional time. Both characteristics of the criterion were rated a "2". The SLR method was generated from complex computer simulations. These programs were not considered a computer version of the SLR method because they were used only to generate data. There is little relationship to the analysis technique, because computer simulations use network node analysis methods.

Summary

Table 5 gives a summary of the scoring results for the SLR method. The index number was 10.88.

The package overall was good. It included both the performance and economic aspects of the proposed passive system. Also, the derivation of the major relationships was shown. One weakness of the package was the lack of

Table 5

Selection Model Scoring Sheet

Name of Method Solar Load Ratio Method	(1) Raw Rating	(2) Criteria Score (AxB)	(3) Weight Factor	(4) Weighted Score (2)x(3)
1. Performance:		8	.178	1.424
A. Provide yearly fractional load	4			
B. Provide average daily indoor temperature fluctuation	2			
2. Economics:		9	.178	1.602
A. Provide B/C Ratio	3			
B. Provide E/C Ratio	3			
3. Flexibility:		16	.169	2.704
A. Handle direct gain systems	4			
B. Handle indirect gain systems	4			
4. Usability		16	.164	2.624
A. Take little time	4			
B. Simple procedure	4			
5. Implementation:		12	.160	1.920
A. All information in package	3			
B. Inexpensive	4			
6. Computing device:		4	.151	0.604
A. Computer version available	2			
B. Package is interactive	2			

INDEX NUMBER[Σ(4)] = 10.878

sufficient instructions on how to work through the worksheets. The worksheets had instructions on them, but they were not sufficient enough for completely explaining the procedure. The provided instructions were adequate for the user who is very familiar with the procedure and needs only a reminder.

The package would be difficult to understand for people new to the field. The package deals specifically with the method of analysis.

The SLR method is a quick and easy way to evaluate a passive solar heating system. The analytic procedure was based on empirical data generated from complex hour-by-hour computer simulations (15:2).

RESISTANCE NETWORK DESIGN METHOD

The Resistance Network Design (RND) method was developed by W. A. Monsen, S. A. Klein, W. A. Beckman, and D. M. Utzinger at the Solar Energy Laboratory, University of Wisconsin, Madison, Wisconsin.

The method utilizes a heat transfer approach. The passive system was first modeled by TRNSYS program using a thermal network (14:19). After making three assumptions, the model was reduced to a simple linear network.

Two parameters, U_1 and U_w , represent the design characteristics. U_1 is the heat transfer coefficient from the outside air to the thermal storage wall, and U_w is the

heat transfer coefficient from the storage wall to the indoor living space (14:120). The above parameters are for indirect gain systems. For direct gain systems, only U_1 is needed (14:120).

The method has been validated by computer simulation. The biggest advantage of this method is that it can handle varying number of glazings, glazing properties, wall thicknesses, wall thermal properties, and nighttime insulation without loss of accuracy (14:120).

Evaluation

Performance. The RND package only addressed monthly average of daily solar energy entering the building (14:120). The annual solar heating fraction (SHF) can be calculated from the data, but is not discussed in the package. Therefore, the RND package received a "3" for the "Annual fractional load" criterion characteristic.

The RND package assumes a 10°F allowable temperature fluctuation (14:119). The effects of low temperatures appear in the auxiliary heating requirement. Unacceptably high temperatures are accounted by finding the energy vented or energy needed to cool the building. Since the temperature fluctuation is indirectly considered, the "average daily temperature fluctuation" criterion characteristic received a "3".

Economics. The economic aspects were not mentioned and thus received a "2" in both characteristics. An economic analysis could be added to the package, but a relatively large amount of time would be needed.

Flexibility. The RND package can handle both direct and indirect gain systems (14:119). Therefore, it received a "4" for both characteristics of this criterion.

Usability. The procedure is simple and takes a little time to work through. There are few equations but preparing the input for them may be time consuming. For example, the transmittance-absorptance product ($\overline{\alpha\tau}$) is needed to calculate the solar radiation absorbed by the wall (14:120). The calculation of this product is not addressed in the package, but it can become very complex if accuracy is wanted.

An iterative process is required to calculate the U_1 and wall temperature of the storage wall system (14:120). The authors of the package insist the iterative process converges rapidly (14:120). Some knowledge of heat transfer is needed to initially understand the equations.

Both characteristics of the "Usability" criterion received a "4".

Implementation. The RND method was not designed to be used independently of other methods (14:119). Several other sources are needed to provide a complete package. The "all information in package" criterion characteristic received a "2".

The package that was evaluated would be inexpensive to implement. Therefore, the "Inexpensive" criterion characteristic received a "4".

Computing device. The more complex version (TRNSYS) which validated the method is a computer simulation (14:119). However, there is not a computer version of the method as presented in the package. Both characteristics received a "2".

Summary

Table 6 is a summary of the scoring for the RND package. The index number for this package is 9.53.

The authors of this thesis realize that the package was evaluated based on a purpose inconsistent with the purpose of the RND method. Its purpose was to discuss an alternative to the Solar Load Ratio method, not to provide a complete analysis technique package (14:119). However, it was felt that in order to evaluate the RND method consistent with the other methods, it should be evaluated the same way as the other methods.

The advantage of the package is its flexibility, while its accuracy depends on the truthfulness of the major assumptions. The authors of the RND method feel their method is conservative, that is, it tends to underestimate the performance of the passive solar system (14:119).

Table 6

Selection Model Scoring Sheet

Name of Method Resistance Network Design	(1) Raw Rating	(2) Criteria Score (AxB)	(3) Weight Factor	(4) Weighted Score (2)x(3)
1. Performance:		9	.178	1.602
A. Provide yearly fractional load	3			
B. Provide average daily indoor temperature fluctuation	3			
2. Economics:		4	.178	0.712
A. Provide B/C Ratio	2			
B. Provide E/C Ratio	2			
3. Flexibility:		16	.169	2.704
A. Handle direct gain systems	4			
B. Handle indirect gain systems	4			
4. Usability		16	.164	2.624
A. Take little time	4			
B. Simple procedure	4			
5. Implementation:		8	.160	1.280
A. All information in package	2			
B. Inexpensive	4			
6. Computing device:		4	.151	0.604
A. Computer version available	2			
B. Package is interactive	2			

INDEX NUMBER[$\Sigma(4)$] = 9.526

RULES OF THUMB "PATTERNS" METHOD

The Rules of Thumb "Patterns" Method was developed by Edward Mazria of Albuquerque, New Mexico. The package evaluated in this thesis is a book authored by E. Mazria entitled, The Passive Solar Energy Book (12; 13). There are two versions of this book, one is subtitled "A complete guide to passive home, greenhouse and building design," (12) and the other "Expanded Professional Edition" (13).

The patterns are identical in both versions. The expanded edition has a more detailed explanation of the "fine tuning" equations as well as more charts and graphs.

There are two parts to the procedure. The first part is the patterns, which are rules of thumb guidelines and recommendations for developing a basic design. There are 27 patterns but not all apply to each design situation (12:69). For example, if a direct gain system is desired, 8 patterns immediately do not apply because they are for other types of systems. Table 7 lists the 27 patterns.

The second part is fine tuning, which takes the basic design and "fine tunes" it to the most optimal dimensions (12:309-394). The six steps for fine tuning are listed in Table 8.

Evaluation

Performance. Both the monthly and yearly solar heating fraction (SHF) are calculated in the patterns package. The

Table 7

The Patterns

1. Building Location
2. Building Shape
3. North Side
4. Location of Indoor Spaces
5. Protected Entrance
6. Window Location
7. Choosing the System
8. Appropriate Materials
Direct Gain Systems
9. Solar Windows
10. Clerestories and Skylights
11. Masonry Heat Storage
12. Interior Water Wall
Thermal Storage Wall Systems
13. Sizing the Wall
14. Wall Details
Attached Greenhouse Systems
15. Sizing the Greenhouse
16. Greenhouse Connection
Roof Pond Systems
17. Sizing the Roof Pond
18. Roof Pond Details
Greenhouse
19. South-Facing Greenhouse
20. Greenhouse Details
21. Combining Systems
22. Cloudy Day Storage
23. Movable Insulation
24. Reflectors
25. Shading Devices
26. Insulation on the Outside
27. Summer Cooling

(12:66-266)

Table 8

Fine Tuning

STEP 1:	Calculating the rate of space heat loss.
STEP 2:	Calculating space heat gain.
STEP 3:	Determining the average daily indoor temperature.
STEP 4:	Determining the daily indoor temperature fluctuation.
STEP 5:	Calculating the auxiliary space heating requirements.
STEP 6:	Determining the cost effectiveness of the system.

[12:309-344]

procedure is based on the solar load ratio method (SLR) developed by J. D. Balcomb and R. D. McFarland (12:328). The "annual fractional load" criterion characteristic received a "4".

In step 4 of the fine tuning, the expected daily indoor temperature fluctuation is determined. The fluctuation is derived from the daily average indoor temperature and a graph of the temperature fluctuation for the type of system being designed. The daily average indoor temperature serves as a reference on the graph. A curve is generated for the passive system following the appropriate curve on the graph while maintaining a constant difference for each hour.

The "temperature fluctuation" criterion characteristic received a "4".

Economics. The Patterns package provides an equation that calculates the cost of solar heat per Btu and a nomograph which yields the years to break even (12:341-344). This calculation is performed in step 6 of fine tuning. The nomograph is based on 8% interest, and 1% maintenance per year. Most economic analyses in the Air Force require 10% interest, thus making the provided nomograph inaccurate.

The E/C ratio is provided but in reciprocal form. The B/C ratio is not provided. The additions needed to provide the ratios would be relatively easy to incorporate into the method. Both characteristics of the "Economics" criterion received a "3".

Flexibility. The Patterns package is extremely flexibile. It can handle both direct and indirect gain systems. Because of this capability, it received a "4" for each criterion characteristic.

Usability. The procedure is very simple for the patterns with only a slight increase in complexity for the fine tuning. The book is lengthy, but once the user is familiar with the order in the book, the procedure should not take long. The entire sizing procedure, patterns, and fine tuning, should

not exceed two to three hours. Both characteristics received a "4" for this criterion.

Implementation. The package is complete and comprehensive. All necessary information is in the book. Some of the more complex variables have been simplified into constants, tables, or graphs. If a user feels uncomfortable with the simplification, he may go to another source, but the values given in the book are good enough for reasonable accuracy. The "all information in package" criterion characteristic received a "4".

The books are moderately expensive. The guide version sells for $11 while the expanded version costs $25. In accordance with the rating scale for the "Inexpensive" criterion characteristic, the package received a score of "3".

Computing device. The method is not available on computer. To make it available would be difficult since the method is mostly rules of thumb. However, due to increased storage capacity in modern computers, the method would be possible to put on a computer and make it interactive with the user. Both characteristics received a "2" for this criterion.

Summary

Table 9 lists the scoring for the Patterns package. The index number for the package was 12.302.

Table 9

Selection Model Scoring Sheet

Name of Method Rules of Thumb Patterns	(1) Raw Rating	(2) Criteria Score (AxB)	(3) Weight Factor	(4) Weighted Score (2)x(3)
1. Performance:		16	.178	2.848
A. Provide yearly fractional load	4			
B. Provide average daily indoor temperature fluctuation	4			
2. Economics:		9	.178	1.602
A. Provide B/C Ratio	3			
B. Provide E/C Ratio	3			
3. Flexibility:		16	.169	2.704
A. Handle direct gain systems	4			
B. Handle indirect gain systems	4			
4. Usability		16	.164	2.624
A. Take little time	4			
B. Simple procedure	4			
5. Implementation:		12	.160	1.920
A. All information in package	4			
B. Inexpensive	3			
6. Computing device:		4	.151	0.604
A. Computer version available	2			
B. Package is interactive	2			

INDEX NUMBER[Σ(4)] = 12.302

The Passive Solar Energy Book is very easy to understand and is comprehensive. The major advantage of this package is its simplicity. The weakness of the package is the length, 435 pages for the short version. However, the patterns are highlighted in bold type to allow quick reading. By reading only the bold type, the book can be read in an hour (12:4).

TROMBE WALL LOAD ANALYSIS METHOD

Doug Kelbaugh, architect and solar consultant of Princeton, New Jersey, and John Tichy, assistant professor of Mechanical Engineering at Rensselaer Polytechnic Institute, have proposed a simplified thermal load analysis technique for Trombe wall passive solar heating systems. The method is based on the calculations of heat which is radiated back through the wall glazing by means of an "empirically determined dynamic U-factor which depends on solar radiation and ambient temperature [10:403]." The authors go on to state that the method is similar to familiar ASHRAE methods. The results are reported by D. Kelbaugh and J. Tichy to be consistent with, although somewhat less conservative than the Los Alamos Scientific Laboratory Solar Load Ratio Method.

The authors feel the need for this package based on some apprehension among passive architects and designers with the unfamiliar approach used in the Los Alamos methods.

The technique proposed by Kelbaugh and Tichy is a simplified method which allows the Trombe wall to be treated like conventional heat load calculations.

One characteristic of this program is what the authors term as "quasi-steady" application. That is, it considers a time period of one month which is longer than the usual time constant of the building so that temperature fluctuations can be averaged. This time period is also short enough that climactic variables do not undergo large seasonal variations (10:403).

A second characteristic of this program is that it considers the energy balance of the entire building, whereas the Los Alamos studies consider the Trombe wall to be a separate energy supply to the rest of the building. Under this method, wall solar heat gain is calculated using the average monthly horizontal insulation, or standard ASHRAE solar gain tables which have been modified by a cloudiness factor.

The advantage of this system is its simplicity in predicting the performance of the Trombe wall passive solar heating system. The main disadvantage is that it is based on the Trombe wall, for it does not offer the versatility of many of the other systems, nor the versatility which the authors of this thesis are looking for in defining an acceptable package for use by the Air Force.

One last point which should be taken into account is the fact that this program was validated based primarily on the results of one particular building in one climate region. Hopefully, the work will be expanded and tested more thoroughly in the future.

Evaluation

The evaluation of the thermal load analysis method for Trombe wall passive solar heating systems will follow the selection model reviewed earlier in the thesis.

Performance. The first criterion to be examined is Performance. The first criterion characteristic, to provide a yearly fractional load, is met by this method; therefore, this package receives a "4" in this criterion characteristic. However, the package does not calculate the average daily indoor temperature fluctuations. These temperature fluctuations can be derived fairly easily from the information that is given in the package. For this reason, the authors of this thesis give the second criterion characteristic a score of "3".

Economics. The second criterion deals with the Economics of the package. The method does not make any mention of economics in the package. In keeping with the scoring procedure, the authors of this thesis award packages which do not describe any economic analysis with scores of "2" for

both criterion characteristics, that of providing the B/C ratio and the E/C ratio.

Flexibility. Flexibility is the third criterion, and it is this area which greatly hinders this method. The package reviewed deals exclusively with Trombe walls. It does not mention the direct gain system as K. Kelbaugh believes enough packages already address the direct gain system. This may be true, but a package which adequately handles both direct gain systems as well as indirect gain systems is needed. The exclusivity of this package forces the authors of this thesis to give it a "1" for the criterion characteristic of handling direct gain systems, the lowest grade psosible. The Trombe wall system is only one form of indirect gain system, and for this reason, the package only receives a "3" on the second criterion characteristic. The total criteria score of "3" under Flexibility is a definite indicator of the limits of this method.

Usability. The fourth criteria is the method's usability. This is one of the advantages of this method. It is simple to understand and simple to apply. It also is a comparatively short model, and the average designer should have no trouble in completing the calculations within the three hour time span necessary for the highest score under the criterion characteristics, takes little time. For these reasons, both

criterion characteristics under the criteria of Usability receive scores of "4".

Implementation. The fifth criteria is Implementation. The calculations in the program require the use of ASHRAE tables for many values, but this is relatively easy to obtain. The criterion characteristic "all information in package" received a score of "3". The cost of the technique is in the range equivalent to a score of "4" for the criterion characteristic of inexpensive.

Computing device. Computing devices are not mentioned. To develop a computer program based on this technique would be both costly and time consuming. Both criterion characteristics under Computing device receive scores of "2".

Summary

As stated before, the Trombe Wall Load Analysis Method does a very good job of what it intends to do. However, the scope of the method is too restrictive to be of value to the Air Force at this time. The index for this method is 8.503. Table 10 summarizes the scoring procedure.

LAWRENCE BERKELEY LABORATORY MODELING METHOD

The Energy and Environment Division of the Lawrence Berkeley Laboratory at the University of California, under the direction of David B. Goldstein, has designed hand

Table 10

Selection Model Scoring Sheet

Name of Method Trombe Wall Load Analysis Method	(1) Raw Rating	(2) Criteria Score (AxB)	(3) Weight Factor	(4) Weighted Score (2)x(3)
1. Performance:		12	.178	2.136
A. Provide yearly fractional load	4			
B. Provide average daily indoor temperature fluctuation	3			
2. Economics:		4	.178	.712
A. Provide B/C Ratio	2			
B. Provide E/C Ratio	2			
3. Flexibility:		3	.169	.507
A. Handle direct gain systems	1			
B. Handle indirect gain systems	3			
4. Usability		16	.164	2.624
A. Take little time	4			
B. Simple procedure	4			
5. Implementation:		12	.160	1.92
A. All information in package	3			
B. Inexpensive	4			
6. Computing device:		4	.151	.604
A. Computer version available	2			
B. Package is interactive	2			

INDEX NUMBER[Σ(4)] = 8.503

calculations to model passive solar buildings. According to the authors, the hand calculation model will predict the temperature responses inside a building based on the design parameters of the building and climactic data. The model is used most effectively to determine the room temperature during different times of day. The calculations can be used both on direct gain systems and on Trombe-wall and waterwall systems. The model was developed at the Lawrence Berkeley Laboratory as part of a research project on analytic building calculations. This project had been initiated by Samuel Berman at the laboratory and Robert Richardson of New York University (8:165).

Goldstein further states that the hand calculations included in this model are actually more accurate than the major computer programs now available in their predictions of the indoor temperature responses throughout the day. The explanation given for this is that the computer models do not look at the distribution of the solar energy throughout the room. According to Goldstein, the computer programs correctly calculate the solar gain through the window, but the heat gain is then spread out over all surfaces on the inside of the room. On the other hand, the hand calculations let the user specify the proportional amounts of solar heat to be absorbed on each interior surface (8:164).

Probably the biggest disadvantage to this method is stated directly by David Goldstein. He recommends that

the hand calculations be written for a progammable calculator and believes that left in their original form, they may be too complex for the designer to use effectively.

The surface temperature of each surface is determined by an equation which equates the heat losses from the surface to the heat gain of the particular surface. The equation is as follows:

$$h_j A_j (T_{s_j} - T_R) - A_j K_j \left.\frac{\delta T_j(x,t)}{\delta x}\right|_{x=0} = \alpha_j S$$

where

h_j = the combined radiation/convection film heat transfer coefficient for the j^{th} surface (watts $m^{-2} {}^\circ C^{-1}$ or Btu $hr^{-1} ft^{-2} {}^\circ F^{-1}$).

A_j = the area of the surface (m^2 or ft^2).

T_R = the room temperature.

$T_j(x,t)$ = the temperature distribution within the j^{th} material.

K_j = is the conductivity of the j^{th} material (watts $m^{-1} {}^\circ C^{-1}$ or Btu $hr^{-1} ft^{-1} {}^\circ F^{-1}$).

αj = the fraction of sunlight absorbed on the j^{th} surface.

x = the distance into the material.

S = the total amount of sunlight entering the building (in watts or Btu hr^{-1}) (8:165).

Within the material, heat flow is measured by the following diffusion equation:

$$K_j \frac{\sigma^2 T_j(x,t)}{\sigma x^2} = (pc)_j \frac{\sigma T_j(x,t)}{\sigma t}$$

where

$(pc)_j$ = the heat capacity per unit volume of the j^{th} material (Joules $^oC^{-1}m^{-3}$ or Btu $^oF^{-1}$ ft^{-3}) (8:165).

In this case, a new diffusion equation is used for each layer of material if a surface is composed of different layers.

The surface temperature of the interior surface is then described using the following equation:

$$T_{s_j} = (h_j T_R + \alpha_j S/A_j)R_{1j} + \dot{T}_A R_{2j}$$

where R_{1j} and R_{2j} are frequency-dependent response functions whose forms are given in the model (8:166).

Surface temperatures are then combined into an equation which computes the room temperature.

$$\sum_{j=1}^{N} \hat{h}_j (T_R - T_{s_j}) + \hat{U}_q (T_R - T_A) = H + \alpha_R S$$

where $\hat{h}_j = h_j A_j$ and H is the heater output (8:166).

In the above equation:

α_R = the fraction of sunlight absorbed directly into the room air or on the surfaces of light objects.

$\hat{U}_q$ = the quick heat transfer coefficient, that is, the sum of U-values times areas for all pure conductances such as windows, plus the loss rate due to infiltration.

The model was tested on the solar test cells at the Los Alamos Laboratories. Material properties were taken from ASHRAE handbooks. According to the authors, the room temperature of the solar cells was predicted with less than 10% error over all hours of the day. Increased accuracy is uncertain due to possible errors in the data such as infiltration rates, net transmissivity of the collector windows, etc. (8:168).

Again, probably the biggest problem apparent with this program is the difficulty and the time needed to complete the calculations in the entire program.

Evaluation

Performance. The package does not directly calculate the yearly fractional load, which is the average amount of energy supplied by the system. However, it is comparatively easy to derive this value from the information that is given

with the package. For this reason, the first criterion characteristic under Performance, providing the yearly fractional load, is given a "3".

The second criterion characteristic under Performance is that the program provide the average daily indoor temperature fluctuations. Since the package is designed to derive the indoor temperatures of the building, this criterion is given a grade of "4".

Economics. The second criteria in the selection model is Economics. The method using hand calculations by David B. Goldstein does not address economics. It may difficult to include the B/C ratio and the E/C ratios in this method. Therefore, both criterion characteristics under Economics will receive a score of "2".

Flexibility. The third criteria is Flexibility. The criterion characteristics under Flexibility are based on whether the package handles both direct and indirect gain systems. The authors state that the program can model both direct gain and indirect gain systems, both Trombe and waterwall systems. The method is given a "4" for both the direct and indirect gain systems.

Usability. The fourth criteria, Usability, is a distinct disadvantage for this program. The authors of the model state that if the package were transferred to a programmable

calculator, it could probably be done in ½ hour. However, since the Air Force is not concerned with the programmable calculator method, the criterion characteristic, "takes little time", will be given a score of "3". The authors themselves doubt the simplicity of the procedure of the model for widespread use, so the second criterion characteristic will also be given a score of "3".

Implementation. The fifth criterion, Implementation, also acts to downgrade the effectiveness of this model. All the graphs and tables are not included in this package. As stated before, some of the design specifications must be obtained from the ASHRAE handbook. Therefore, a "3" will be given to the criterion characteristic, "all information in package".

The second criterion characteristic under Implementation is that the package be inexpensive. The method receives a "3" for this criterion characteristic due to an expected cost of between $10 and $50.

Computing device. The last criterion is that the method contain a computing device. The method does not address the possibility of converting the hand methods to a computer. The authors even mentioned the advantages they feel exist in keeping their equations in the original form. This may be an advantage to D. Goldstein, but it is also an advantage to have a computer option available if desired. It would be

Table 11

Selection Model Scoring Sheet

Name of Method Lawrence Berkely Laboratory Modeling Method	(1) Raw Rating	(2) Criteria Score (AxB)	(3) Weight Factor	(4) Weighted Score (2)x(3)
1. Performance:		12	.178	2.136
A. Provide yearly fractional load	3			
B. Provide average daily indoor temperature fluctuation	4			
2. Economics:		4	.178	.712
A. Provide B/C Ratio	2			
B. Provide E/C Ratio	2			
3. Flexibility:		16	.169	2.704
A. Handle direct gain systems	4			
B. Handle indirect gain systems	4			
4. Usability		9	.164	1.476
A. Take little time	3			
B. Simple procedure	3			
5. Implementation:		9	.160	1.44
A. All information in package	3			
B. Inexpensive	3			
6. Computing device:		4	.151	.604
A. Computer version available	2			
B. Package is interactive	2			

INDEX NUMBER[Σ(4)] = 9.072

possible to write a computer version for this method, but it would be both time consuming and expensive. For these reasons, both criterion characteristics under Computing device will be given scores of "2".

Summary

The Selection Model Scoring Sheet shown in Table 11 reviews the scores given for this model. As can be seen, it was hurt chiefly near the bottom of the sheet by the characteristics valued at less than prime importance. The final index is 9.072.

LUMSDAINE SIMPLE DESIGN METHOD

A "Simple Design Calculation Procedure For Passive Solar Houses" is the method designed by Monika Lumsdaine of the Physical Science Laboratory at New Mexico State University and Edward Lumsdaine of the New Mexico Solar Energy Institute at New Mexico State University. Although the design procedure was originally developed specifically for the New Mexico area, it can be used in other areas with the applicable climactic data. According to the authors, the design procedure has been developed with the following needs in mind. First, they felt the need for a simple procedure that could be used by private owners and builders who would be interested in designing their own homes using passive solar features, whether they had a technical background or

not. Second, the authors designed the procedure for those people who would be involved in applications for federal solar grants or financing. Examples of these include Department of Energy, Housing and Urban Development, Federal Housing Administration, where thermal load calculations must be included in forms submitted to the agencies. Last, the procedure can be further simplified to be used as a preliminary design aid for approximations.

The model is effective for both direct gain and indirect gain (whether they be mass or water). The method is recommended for persons who do not have access to a computer. The procedure is comprised of five different worksheets, each with a different function. The first worksheet is used to find the building skin conductance. The design parameters are taken from the building design, and U-values are included in the package typical construction in New Mexico. Values not included can be found in ASHRAE handbooks.

The second worksheet determines the infiltration and building heat loss coefficient. The infiltration is calculated as the volume of the area multiplied by the air changes per hour and the heat capacity of the air, which is dependent upon the altitude. The modified building heat loss coefficient is computed by multiplying the sum of the building skin conductance and the infiltration load by 24 (11:411).

The third worksheet derives the thermal load of the building using the modified building heat loss coefficient

and heating degree day information, which is included in the package for areas within New Mexico. Outside sources must be used in areas not in New Mexico.

The fourth worksheet calculates the recommended collector area based on tables depicting the average solar heat gain in New Mexico.

The last worksheet determines the solar load ratio and the auxiliary load profile. The solar load ratio is the total monthly solar heat gain divided by the monthly net thermal load (11:413). The solar heating fraction is then obtained from a chart included in the package. A monthly solar heating contribution is found by multiplying the solar heating fraction by the net thermal load. Then the auxiliary load profile is calculated by subtracting the solar heating contribution from the net thermal load (11:413).

Evaluation

<u>Performance</u>. The package received the highest score of "4" under the criterion characteristic of providing yearly fractional load, but only received a "3" for the average daily indoor temperature fluctuations. This information is not provided, but could be calculated using some of the data already provided.

<u>Economics</u>. Economic factors are not directly addressed in this program. Therefore, the criterion characteristics have

been giving scores of "2" to both factors. A separate economic analysis would have to be incorporated which could be both expensive and time consuming.

Flexibility. The third characteristic, Flexibility, is highly scored in this method. Since this method addresses both direct gain systems and indirect gain systems, the authors of this thesis feel justified in awarding ratings of "4" to both of the criterion characteristics.

Usability. The fourth criterion, Usability, is the strong point of this package. It has specifically been designed for the individual without a great deal of a mathematics background, although familiarity with the different types of passive heating techniques is necessary. According to the authors, simplicity does not appreciably sacrifice the accuracy of the model. On both criterion characteristics under Usability, this procedure scores a "4".

Implementation. The fifth criteria is Implementation, and this does present some weaknesses, although minor, for this package. The information in this package is only valid for passive solar systems located in New Mexico. Fortunately, however, the information which this package provides only for the state of New Mexico is readily available to the general public. Therefore, the first criterion characteristic, "all information in package", receives a score of "3".

The procedure is published; therefore, it is available at a relatively inexpensive price. A score of "3" will be given for this criterion characteristic, in accordance with the guidelines previously mentioned in the first part of the thesis.

Computing device. Computer versions have not been discussed by either author. The amount of difficulty to implement a computer version could be great; therefore, this program received a score of "2" for both criterion characteristics, the availability of a computer version, and an interactive package.

Summary

The simple Design Calculation Procedure for Passive Solar Houses designed by Monika and Edward Lumsdaine at New Mexico State University is a very basic program, designed for those individuals who may not be equipped with the technical background necessary to perform some of the calculations in many other procedures. The final index score is 10.22. The raw ratings and scores are summed up in Table 12.

PASSIVE SOLAR DESIGN HANDBOOK

The Passive Solar Design Handbook, Passive Solar Design Analysis is volume 2 of a two volume set prepared in January, 1980, for the U.S. Department of Energy, Office of

Table 12

Selection Model Scoring Sheet

Name of Method Lumsdaine Simple Design Method	(1) Raw Rating	(2) Criteria Score (AxB)	(3) Weight Factor	(4) Weighted Score (2)x(3)
1. Performance:		12	.178	2.136
A. Provide yearly fractional load	4			
B. Provide average daily indoor temperature fluctuation	3			
2. Economics:		4	.178	.712
A. Provide B/C Ratio	2			
B. Provide E/C Ratio	2			
3. Flexibility:		16	.169	2.704
A. Handle direct gain systems	4			
B. Handle indirect gain systems	4			
4. Usability		16	.164	2.624
A. Take little time	4			
B. Simple procedure	4			
5. Implementation:		9	.160	1.44
A. All information in package	3			
B. Inexpensive	3			
6. Computing device:		4	.151	.604
A. Computer version available	2			
B. Package is interactive	2			

INDEX NUMBER[Σ(4)] = 10.22

Solar Applications. It was prepared by the Los Alamos Scientific Laboratory and the University of California. The main contributors to this work are J. Douglas Balcomb, Dennis Barley, Robert McFarland, Joseph Perry, Jr., William Wray, and Scott Noll. The handbook is a very comprehensive analysis of passive solar design.

The handbook contains three different phases. The first phase is a simplified procedure for buildings in the developmental phase. The second two phases are more detailed analysis methods for the actual construction specifications.

The technical evaluation and analysis of the models have been primarily based on the PASOLE, passive solar energy, computer code, which was written by Robert McFarland. Mr. McFarland also developed the analysis of the thermal storage walls, as well as solar radiation correlations. Evaluation and analysis of direct gain systems was directed by William Wray, with the use of SUNSPOT, a model of PASOLE. Monthly solar savings calculations are by Joseph Perry, Jr. The economic analysis was developed by Scott Noll and Dennis Barley.

The primary measure of passive solar effectiveness in this book is the Solar Saving Fraction (SSF) which is defined in the following manner:

$$SSF = \frac{\text{solar savings}}{\text{reference net thermal load}}$$

$$SSF = 1 - \frac{\text{auxiliary heat required by the solar bldg}}{\text{auxiliary heat req'd by comparable nonsolar bldg}}$$

The Solar Saving Fraction replaces the Solar Heating Fraction used in the Solar Load Ratio method. The difference between the two values is that the Solar Heating Fraction is based on the actual floating temperature in the building rather than the desired temperature. Values of the Solar Saving Fraction are usually lower than the original Solar Heating Fraction (3:10-11). The SSF is regarded by J. Balcomb as a more accurate measure of actual energy saved (see Appendix B for an example of the method).

The first to be reviewed is a monthly solar savings calculation. This is defined as "a month-by-month estimate of the solar savings using the Los Alamos Scientific Laboratory Monthly Solar Load Ratio Method based on correlations for the various system types [3:133]."

The second technique to be reviewed is the temperature swing estimation for a direct gain building. According to the handbook,

> This procedure calculates the 'Diurnal Heat Capacity' of the building based on accounting for the characteristics of each internal surface and then uses this to estimate temperature swing [3:133].

The economics of the handbook are very comprehensive. The authors explain some of the economic principles unique to a solar house, and the interrelationships among different investment alternatives. Cost evaluation and cost

optimization are explored within the economic analysis. Life cycle costing is used to compare uniform annual costs between different options present to the builder of a solar building, as well as cost comparisons to a nonsolar building. Although the economics do not directly compute the E/C ratio and the B/C ratio, their life cycle costing, as well as the inclusion of present value formulas, enable an easy transfer to these ratios.

Evaluation

Performance. The first criterion is Performance. The two criterion characteristics under performance are that the program provide a yearly fractional load and an average daily indoor temperature fluctuation. The Passive Solar Design Handbook is one of the few programs that actually does both criterion characteristics within the programs themselves. Therefore, both criterion characteristics under Performance receive a score of "4".

Economic. The second criterion is Economics. Although the programs do not explicitly provide for the B/C ratio and E/C ratio, they do have a very complete economic analysis using life cycle costing and net present value. From doing the economic analysis in the package, it would be simple to compute the two ratios. In following with the scoring procedure, both criterion characteristics received scores of "3".

Flexibility. The third characteristic evaluated in the selection model is Flexibility. The Passive Solar Design Handbook handles both passive solar systems with equal ease and accuracy. Both criterion characteristics therefore received a score of "4".

Usability. The fourth characteristic is Usability. In looking at the usability of a specific model, we are concerned with its effect on the user. Two criterion characteristics reflect this concern. The first criterion characteristic notes if the program takes little time. A three hour time limit has been set for a technique to receive a score of "4", and both techniques in the handbook meet that requirement. The second criterion characteristic is that the procedure is simple to understand and apply. The handbook meets this requirement very well. Examples are included in the chapters, and the methods are very easy to follow. A score of "4" is also given for this criterion characteristic.

Implementation. The fifth characteristic is Implementation, and is a direct indication of the ease with which the Air Force would be able to introduce the package to its base level operations. The first criterion characteristic under Implementation is "all information is in the package". This is one package which included all the tables and graphs necessary to complete the calculations of design performance. A score of "4" is given for the first characteristic. The

second criterion characteristic is the cost of the system. The cost of the handbook lists at $14. However, if bought in bulk, a reduction in cost to the Air Force seems likely. Thsi cost places the package in a category which gives it a score of "4" on this characteristic.

Computing device. The last criteria to be investigated under the selection model procedure is the computing device. The first criterion characteristic is that a computer version is available and the second characteristic is that the package be interactive. The Handbook does not mention any information about proposed or existing computer packages based on this program. The implementation of a computer version would be possible, but it could be difficult and costly. Both criterion characteristics are given a score of "2" for this reason.

Summary

The final index is 12.942. A quick review of the package indicates that the only substantial deficiency was the absence of a computer version. The other two areas which did not receive a top score were Economics, and the inexpensive criterion characteristic under Implementation. The cost is still a low $14 per copy, and the economic analysis that the program does provide is quite complete itself. Neither of these are very serious weaknesses, and can be improved quite easily. Table 13 summarizes the results.

Table 13

Selection Model Scoring Sheet

Name of Method Passive Solar Design Handbook	(1) Raw Rating	(2) Criteria Score (AxB)	(3) Weight Factor	(4) Weighted Score (2)x(3)
1. Performance:		16	.178	2.848
A. Provide yearly fractional load	4			
B. Provide average daily indoor temperature fluctuation	4			
2. Economics:		9	.178	1.602
A. Provide B/C Ratio	3			
B. Provide E/C Ratio	3			
3. Flexibility:		16	.169	2.704
A. Handle direct gain systems	4			
B. Handle indirect gain systems	4			
4. Usability		16	.164	2.624
A. Take little time	4			
B. Simple procedure	4			
5. Implementation:		16	.160	2.560
A. All information in package	4			
B. Inexpensive	4			
6. Computing device:		4	.151	.604
A. Computer version available	2			
B. Package is interactive	2			

INDEX NUMBER[Σ(4)] = 12.942

Chapter 4

FINAL RESULTS

Table 14 and 15 show the results of scoring for each package. Table 14 has the raw rating for each criterion characteristic, while Table 15 has the criterion scores.

The Passive Solar Design Handbook and Rules of Thumb Patterns packages received the highest indexes, 12.942 and 12.302, respectively. The above packages rated better than the rest of the packages, showing they are the best suited for use in the Air Force. However, the indexes are relatively close for the above packages. This closeness necessitated a subjective comparative analysis to be performed on the Handbook and Patterns packages. The following is the comparison. Some of the other packages scored close to each other, but their comparison with each other was irrelevant since they were not near the highest index.

Subjective Comparative Analysis

The basic difference between the Patterns and Handbook packages is their focus. The Patterns package focuses on the user who is new to the area or not interested in a large quantity of technical detail. The Handbook is oriented to the user who has some background in the area and has

Table 14

Summary of Criterion Characteristic Scores for All Methods

Criterion Characteristic / Method of Analysis	Solar Load Ratio Method	Resistance Network Design Method	Rules of Thumb Patterns Method	Trombe Wall Load Analysis Method	LBL Modeling Method	Lumsdaine Simple Design Method	Passive Solar Design Handbook Method
Performance							
Annual fraction load	4	3	4	4	3	4	4
Temperature fluctuations	2	3	4	3	4	3	4
Economic							
E/C ratio	3	2	3	2	2	2	3
B/C ratio	3	2	3	2	2	2	3
Flexibility							
Direct gain	4	4	4	1	4	4	4
Indirect gain	4	4	4	3	4	4	4
Usability							
Time	4	4	4	4	3	4	4
Simplicity	4	4	4	4	3	4	4
Implementation							
Completeness	3	2	4	3	3	3	4
Cost	4	4	3	4	3	3	4
Computing device							
Computer version	2	2	2	2	2	2	2
Interactivity	2	2	2	2	2	2	2
INDEX	10.878	9.526	12.302	8.503	9.072	10.220	12.942

Table 15

Summary of Criteria Scores for All Methods

Criteria \ Methods of Analysis	Solar Load Ratio Method	Resistance Network Design Method	Rules of Thumb Patterns Method	Trombe Wall Load Analysis Method	LBL Modeling Method	Lumsdaine Simple Design Method	Passive Solar Design Handbook Method
Performance	8	9	16	12	12	12	16
Economics	9	4	9	4	4	4	9
Flexibility	16	16	16	3	16	16	16
Usability	16	16	16	16	9	16	16
Implementation	12	8	12	12	9	9	16
Computing Device	4	4	4	4	4	4	4
INDEX	10.878	9.529	12.302	8.503	9.072	10.220	12.942

interest in technical detail. The Handbook has two volumes, the first of which can inform the user of passive solar concepts and theories before entering into the technical aspects of designing.

Another difference is the publishing organization. The Patterns package, which is the book The Passive Solar Energy Book, is published by Rodale Press. Compensation close to the selling price of the book could probably be requested by the publisher if this package would be used in the Air Force. The Passive Solar Design Handbook, the text for the Handbook package, is published by the Government Printing Office for the Department of Energy. Use of this package would be less expensive to the Air Force.

Both packages are comprehensive, no additional sources are needed for information. The parameters in the Patterns package have been greatly simplified. The technically oriented user may be uncormfortable in using only the information in the Patterns package. The Handbook is more detailed. The parameters are basically the same in both packages, but the handbook presents them in a more precise manner. This better precision is achieved via the sensitivity analysis. This analysis varies the parameters to show their effects upon the overall performance. For example, the direct gain was analyzed for the effects of thermal storage mass, thermal storage absorptance, number of

glazings, absorption in lightweight objects, and temperature bounds. The analysis for the thermal storage wall involves 14 parameters.

The Patterns package is easier to use. The user only has to run through the relevant patterns to obtain the basic design, then a six step procedure for "fine tuning" the design. Although the Handbook is also simple, it is slightly more complex because of the technical detail.

The Handbook provides worksheets and examples of their use. The worksheets eliminate much of the "digging through the book" for information which is required for the Patterns package.

J. D. Balcomb in the Handbook states his interest in continuing the research into increasing the capabilities of the package, and continuously updating the package as more information is obtained. The long list of contributors suggests that future information will be available. The above statement is not to be interpreted as meaning that E. Mazria is not interested in future information. Updated versions of the Patterns package are likely since the area is still growing, but this was not expressed in the package.

The only differing performance parameter is the fraction of energy provided by the passive system. The parameter used in the Patterns package is the solar heating fraction (SHF). It is a function of the solar load ratio (SLR). The Handbook package presents the Solar Saving

Fraction (SSF), which is the difference in auxiliary heating requirements with and without the passive system. J. D. Balcomb in the Handbook states that the SSF is more accurate in describing the performance of the system. This statement is believed to be unbiased since he also developed the SHF concept.

The Handbook package goes into greater detail in the economic analysis. The Patterns package presents a nomograph and a short equation for the economic analysis. The Handbook develops the life cycle cost which includes cost of the system and any added energy conservation costs. The time value of money and fuel price inflation are considered in the Handbook in slightly more detail than the Patterns package. Also, worksheets are provided to derive the cost of the passive system.

The results of the comparative analysis show that the Handbook package would be best suited for use in the Air Force. This result is consistent with the scoring model results, which yield the Handbook package with the highest index.

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A REVIEW OF THE METHODS FOR PASSIVE SOLAR SYSTEMS ANALYSIS.(U)
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Chapter 5

CRITIQUE OF THE SELECTION MODEL

The selection model was derived and used specifically for the thesis topic. Since the authors of this thesis were the only people actively involved in the development of the model and scoring of the methods, a total disavowing of possible biasness is impossible. However, this common fallacy in research was of major concern. This chapter is a discussion of the validity, reliability, and practicality of the model. It is felt that weaknesses in the selection model will appear during this discussion.

> Validity refers to the extent to which a test [the model and its criteria] measures what we actually wish to measure. Reliability has to do with the accuracy and precision of a measurement procedure . . . . Practicality is concerned with a wide range of factors of economy, convenience, and interpretability . . . [6:119-120].

Validity

The selection model was to select the best method for passive solar system analysis for use in the Air Force. The absolute proof of the above statement is very difficult. This proof would necessitate an evaluation be performed several years after the implementation of the recommended package. The best proof that can be offered at this time is that the selection model points out the advantages of the

"best" package over the other packages. Table 14 and 15 show the advantages of the Handbook package based on the criterion characteristics and the criteria, respectively. Only the Patterns package had an index close to the index of the Handbook package. The closeness of the index numbers necessitated the subjective comparative analysis in the final results chapter. The results were similar, indicating some validity.

The selection model deals only with passive solar heating systems of the direct and indirect gain type. This restriction tends to question the validity of applying this model to cooling systems and more exotic designs like isolated or hybrid systems. However, all the packages evaluated were for designs that stayed within the above restriction.

Within the scope defined in this thesis, the selection model was a valid tool.

Reliability

There are two aspects to reliability: stability and equivalence (6:123). The stability is a measure of how consistent the measurements are when repeated. The rating is performed by the same individual in each repetition. The equivalence is a measure of how consistent the measurements are if performed by several different raters at the same time. Neither aspect was directly checked. However, the scoring procedure was defined as rigidly as possible to maintain both aspects of reliability. All the packages were

independently scored by each author of this thesis, then a consensus score derived from the individual scores. The scoring by each author was almost identical for each package. This result indicates the model should be reliable.

Practicality

Practicality deals with how easy and useful the model is to obtaining the objectives. There are three aspects to this area: economy, convenience, and interpretability (6:126).

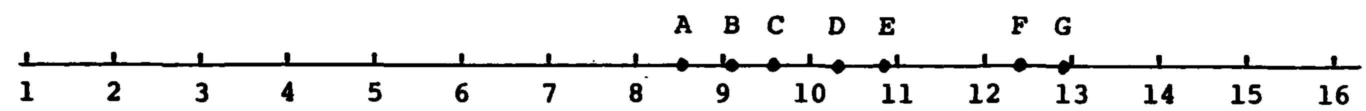
The selection model should not be too expensive to utilize. The selection model as defined in this thesis is very inexpensive. No computer time is required, nor is much time required of the rater. Therefore, the selection model is practical from the "economy" aspect.

The selection model must be easy to understand and convenient for the rater. The selection model scoring sheet is simple to follow and the scoring procedure is straightforward. The rating scheme is a logical set of decision rules. Difficulties in applying the rating scheme to the criterion characteristics were discussed and modified in Chapter 2. It is felt the selection model is practical from the "convenience" aspect.

The last aspect, interpretability, deals with how easily the results can be interpreted. The index scale plays a role in being able to adequately interpret the index

numbers relative to each other. The scale was from 1 to 16, but the index numbers for the packages ranged from 8.5 to 12.9. This narrowness was expected. All the packages were expected to be in the upper half because most of the criteria are required for a good package developed for any use. The index numbers, when plotted on the index scale, show a good relationship between each other and the total spectrum (see Figure 6). The selection model is practical from the "interpretability" aspect.

The selection model was valid, reliable, and practical to the extent discussed above. The major weaknesses of the model are that the model has not been used outside the scope of this thesis, and that the raters were the authors of this thesis. Although, these weaknesses were not eliminated, they were reduced to a minimum. They had little effect on the results and the model's ability to meet the objectives. The authors of this thesis feel the selection model was very adequate in meeting the objectives of this thesis. Further use and development of the selection model is addressed in the recommendations.



A - Trombe Wall Load Analysis Method

B - Lawrence Berkeley Laboratory Modeling Method

C - Resistance Network Design Method

D - Lumsdaine Simple Design Method

E - Solar Load Ratio Method

F - Rules of Thumb Patterns Method

G - Passive Solar Design Handbook Method

Figure 6

Plot of Index Numbers

Chapter 6

CONCLUSIONS/RECOMMENDATIONS

At the beginning of this thesis, three objectives were presented. They were:

1. To design a selection model based on a set of criteria consistent with the needs of the Air Force.

2. To use this selection model to compare existing analysis methods.

3. To recommend an analysis technique which best fits the needs of the Air Force.

A selection model has been designed which is believed to be consistent with the requirements of the Air Force. Six criteria evaluated by the selection model were: performance, economics, flexibility, usability, implementation, and computing device. These criteria were evaluated with concern to implementation in the Air Force.

The second objective has been completed. Seven methods were evaluated according to the specifications set forth in the scoring model. As mentioned in the beginning of the thesis, the methods analyzed were limited to those methods which can be performed with tables, graphs, and equations. This limitation was placed on the methods due to a desire by the Air Force for a method which does not

require expensive hardware such as a programmable calculator. The selection model recommended two specific models as being substantially more complete in terms of fulfilling the needs of the Air Force.

The third objective was fulfilled in the detailed analysis of the final two programs. The results of the detailed analysis confirmed the results presented in the scoring model. The authors of this thesis feel confident in the ability of this program to effectively meet the requirements of the Air Force at a low price.

Recommendations

The authors of this thesis believe that further efforts are necessary in the area of passive solar energy so that a complete program can be established throughout the Air Force. The authors of this thesis, therefore, recommend the following steps be taken in order to insure the success of the work started by this thesis research.

1. That the Air Force adopt as its method for passive solar systems analysis the Passive Solar Energy Handbook, prepared by the Los Alamos Scientific Laboratory and the University of California for the Department of Energy.

2. That further steps be taken to review methods of passive solar systems analysis that use the programmable calculator as the means of computation. The falling cost of

these calculators make this option more and more feasible each year.

3. That further steps be taken to review the methods of passive solar systems analysis that use computer simulation in a manner similar to the evaluation set up in this thesis.

4. That the Passive Solar Energy Handbook be used as a basis for instruction in the Contemporary Energy Applications course at the School of Civil Engineering for the teaching in the area of passive solar system analysis.

5. That a review of the hand methods of passive solar systems analysis be conducted every five years in an effort to decide if any developments in the field of passive solar systems analysis have made it beneficial to change or update the existing system.

The adoption of these recommendations by the Air Force would insure a comprehensive, up-to-date program in the field of passive solar systems analysis. This would insure the success of a program to develop an alternate form of energy for the use of heating many facilities.

APPENDIX A

ABBREVIATIONS

Below is a listing of common abbreviations used in this thesis. All abbreviations have been defined in the text, but these abbreviations (below) appear many times. This listing can be used instead of finding where the abbreviations were defined earlier in the thesis.

B/C Ratio -- Benefit to Cost Ratio

BLC -- Building Load Coefficient

Btu -- British Thermal Unit

DD -- Degree Days °F

E/C Ratio -- Annual MBTU Energy Saved per $1,000 dollar invested

Handbook -- Passive Solar Design Handbook method by J. D. Balcomb

LCR -- Load Collector Ratio

MBTU -- Million Btus

Patterns -- The Rules of Thumb "Patterns" method by E. Mazria

RND -- The Resistance Network method by W. A. Monsen, S. A. Klein, W. A. Beckman, and D. M. Utzinger

SHF -- Solar Heating Fraction

SLR -- Solar Load Ratio

SSF -- Solar Saving Fraction

SPECIAL NOTE: All dimensions in this thesis are in English units.

APPENDIX B

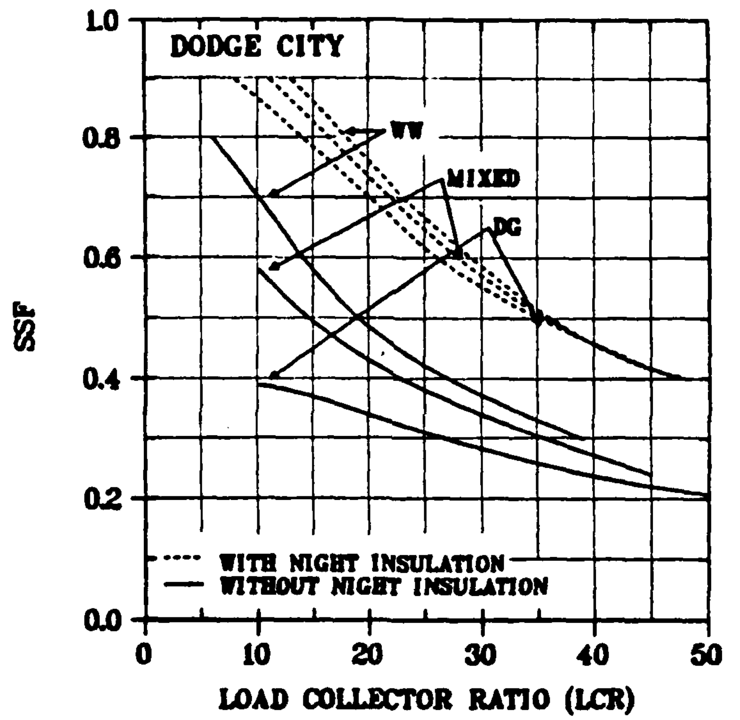
AN EXAMPLE OF THE PASSIVE SOLAR DESIGN HANDBOOK METHOD

The purpose of this appendix is to show some of the worksheets and graphs in the Passive Solar Design Handbook method. It is not intended to completely explain the method, only to present a little more detail since it is the recommended method.

The first of three phases in the design of the passive solar heating system is the schematic design phase. This phase consists of "brainstorming" the potential system design and rules of thumb for developing the basic design.

The second phase, design development, presents a quick and easy procedure. Several iterations can be utilized to converge on an optimal design. A graph such as the one in Figure 7 can be plotted for easy use. The graph contains variables like building heat load and collector area in the Load Collector Ratio (LCR), night insulation, type of system, and solar contribution to the heating demand. The example plotted in Figure 7 is a mixed 40% direct gain and 60% water-wall system in Dodge City, Kansas. If the LCR equals 19, then the SSF would be 75% with R9 night insulation. If the designer wanted to save some money and decides to exclude the night insulation, he could immediately see from Figure 7 that the SSF would decrease to 44%. This decrease of 35 percentage points may be too drastic. The designer then

realizes he can save money on less building insulation. If this decrease in building insulation raises the LCR from 19 to 25, then the SSF would decrease to 65%. From these results, the designer realizes it is better to decrease insulation instead of going without night insulation over the glazing.[3]



[3:43]

Figure 7

Graph of SSF Based Upon LCR

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[3]This is only an example. It should not be taken as a design rule of thumb.

The graph can be used to see what is needed to increase the SSF. For example, the same designer as above decides to use night insulation and cannot improve on an LCR equal to 19, but he wants the maximum SSF. By looking at the graph, he can see that a 100% waterwall will provide a SSF of 78%, higher than the 75% for the mixed system.

Once the design is fairly fixed, then the third phase is started. This phase, the construction documents phase, provides the detailed calculations. This phase considers numerous parameters, and can be used to justify the design. A series of tables and graphs are used in this phase (Tables 16 through 24 and Figures 8 through 13). The "Project Work Sheet" asks for the design specifications, for example all the passive system types, their glazing area, thermostat setting, internal heat generation, and design heating load. Also, calculated values such as BLC, LCR, and Degree-Day base temperature are included. Table "A" derives the solar radiation absorbed by the system taking into account factors such as orientation, tilt, ground reflectance, overhang, transmittance, and absorptance. Table "A" is filled out for each system type.

Table "B" derives the SSF and auxiliary energy requirement. Four worksheets provide help in obtaining input information to Table "B". Worksheet "W1" determines the solar input when more than one system type is used in the design. Worksheet "W2" interpolates the degree-days

Table 16

PROJECT WORK SHEET

Specifications

Project Name Lonesome Pine Residence Date 11/22/79

Location Dodge City, KS Initials JEP

Latitude 37.8°

Passive System Type	Glazing Area	Night Insulation R Value
DG	156 sq ft	R 4
WW	234 sq ft	R 4
	sq ft	R
	sq ft	R

Total Area Ac = 390 sq ft

Thermostat Setting, Tset 70 F

Internal Heat Rate, Qint 40000 Btu/day

Design Heating Load, 20100 Btu/hr

Design temperature: inside 70 F, outside 5 F

Calculated Values

Building Load Coefficient, BLC 7420 Btu/DD, by Method 1 [X], Method 2 [X]

Load Collector Ratio, LCR = BLC/Ac 19.03 Btu/DD sq ft

Degree-Day Base Temperature for Non-solar Building, Tbns 64.61 F

Degree-Days for Non-solar Building, DDns 4960 DD

Degree-Day Base Temperature for Solar Building, Tbs 65.91 F

[3:169]

Table 17. TABLE A) SOLAR RADIATION ABSORBED PER SQUARE FOOT

Location Dodge City, KS Latitude 37.8 Aperture Type DG Collection Area Ac 156 ft^2

Column		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Either HS or VS x Days/Mon	Factors						Product of all Factors	(1) x (8) S
Mon	L-D	Btu / mon sq ft	Orient. =0°	Tilt =90°	Overhang OHR=.250 SEPR=.125 Fig XC-12	Trans-mittance Fig. XC-15	Room absorp-tance DG=1.00			Btu / mon sq ft
Sep	35.0	42510	1.00	1.00	.86	.62	1.00		.533	22666
Oct	46.9	47585	"	"	.94	.67	"		.630	29969
Nov	56.4	41070	"	"	.98	.70	"		.686	28174
Dec	60.9	38998	"	"	.99	.71	"		.703	27412
Jan	59.2	41695	"	"	.98	.71	"		.696	29011
Feb	51.8	41048	"	"	.97	.69	"		.669	27473
Mar	40.6	44516	"	"	.90	.65	"		.585	26042
Apr	28.7	38190	"	"	.80	.60	"		.480	18331
May	19.2	32953	"	"	.75	.57	"		.428	14087
Jun	14.7	31950	"	"	.76	.56	"	JEP	.426	13598

[3:170]

Table 18. TABLE A2 SOLAR RADIATION ABSORBED PER SQUARE FOOT

Location Dodge City, KS Latitude 37.8 Aperture Type WW Collection Area Ac 234 ft^2

Column		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Either HS or VS x Days/Mon	← Factors →						Product of all Factors	(1) x (8) S
Mon	L-D	Btu / mon sq ft	Azimuth 15°W Tilt 90° Fig XC-2		Transmittance Fig XC-15 Az=15°W		Wall absorptance			Btu / mon sq ft
Sep	35.0	42510	1.00		.635		.95		.603	25644
Oct	46.9	47585	.98		.674		.95		.627	29859
Nov	56.4	41070	.97		.697		.95		.642	26379
Dec	60.9	38998	.97		.702		.95		.647	25228
Jan	59.2	41695	.97		.701		.95		.646	26934
Feb	51.8	41048	.98		.687		.95		.640	26254
Mar	40.6	44516	.99		.654		.95		.615	27381
Apr	28.7	38190	1.01		.612		.95		.587	22426
May	19.2	32953	1.03		.580		.95		.568	18702
Jun	14.7	31950	1.05		.568		.95	gsf	.567	18102

[3:171]

Table 19

WORKSHEET W1 AREA-WEIGHTED SOLAR INPUT FOR MULTIPLE SOLAR APERTURES

Location Dodge City, Kansas

	(1)	(2)	(3)	(4)	(5)
Syst	DG	WW	—	—	F1xS1 + F2xS2 + Etc.
Area	156	234			
	S1	S2	S3	S4	S
Const	F1= .400	F2= .600	F3=	F4=	~~JEP~~
Sep	22666	25644			24453
Oct	29969	29859			29904
Nov	28174	26379			27097
Dec	27412	25228			26102
Jan	29011	26934			27765
Feb	27473	26254			26742
Mar	26042	27381			26846
Apr	18331	22426			20787
May	14087	18702			16856
Jun	13598	18102			16300
Sum	236763	246909			242852

[3:173]

Table 20

WORKSHEET W2 DEGREE-DAY INTERPOLATION

Location Dodge City, Kansas

	(1)	(2)	(3)
	T1	T2	Tbs
	65 F	70 F	65.91 F
	DD1	DD2	DD
Const	F1= .817	F2= .183	JLP
Sep	41	118	55.1
Oct	247	382	271.7
Nov	666	816	693.5
Dec	980	1135	1008.4
Jan	1060	1215	1088.4
Feb	834	974	859.6
Mar	738	893	766.4
Apr	344	482	369.3
May	115	218	133.8
Jun	21	51	26.5
Sum	5046	6284	5272

[3:174]

Table 21

WORKSHEET W3,I SOLAR SAVINGS FRACTIONS FOR ARBITRARY R-VALUE OF NIGHT INSULATION

Location Dodge City, Kansas

	(1)	(2)	(3)	(4)
	Table B Col (3)			F1 x (2) + F2 x (3)
	S/DD	SSF DG No NI	SSF DG R9 NI	SSF DG R4 NI
Const		F1= .172	F2= .828	
Sep	444	1.000	.985	.988
Oct	110.1	.894	.973	.959
Nov	39.07	.356	.739	.673
Dec	25.89	.116	.554	.479
Jan	25.51	.108	.547	.472
Feb	31.11	.220	.640	.568
Mar	35.03	.290	.693	.623
Apr	56.29	.576	.866	.816
May	126.0	.934	.979	.971
Jun	615	1.000	.985	.988
Sum		5.494	7.961	7.537

[3:175]

Table 22

WORKSHEET W3,2 SOLAR SAVINGS FRACTIONS FOR ARBITRARY R-VALUE OF NIGHT INSULATION

Location Dodge City, Kansas

	(1)	(2)	(3)	(4)
	Table B Col (3)			F1 x (2) + F2 x (3)
	S / DD	SSF WW No NI	SSF WW R9 NI	SSF WW R4 NI
Const		F1= .247	F2= .753	
Sep	444	.984	.979	.980
Oct	110.1	.954	.978	.972
Nov	39.07	.548	.827	.758
Dec	25.89	.285	.621	.538
Jan	25.51	.277	.613	.530
Feb	31.11	.395	.724	.643
Mar	35.03	.476	.781	.706
Apr	56.29	.756	.929	.887
May	126.0	.967	.979	.976
Jun	615	.984	.979	.980
Sum	JEP	6.626	8.410	7.970

[3:176]

Table 23

WORKSHEET W4 SOLAR SAVINGS FRACTIONS FOR MIXED SYSTEMS

Location Dodge City, Kansas

	(1)	(2)	(3)	(4)	(5)	(6)
Syst Area	Table B Col (3)	DG / 156	WW / 234	___ / ___	___ / ___	F1x(2) + F2x(3) + Etc.
	S / DD	SSF1 R 4 NI	SSF2 R 4 NI	SSF3 R ___ NI	SSF4 R ___ NI	SSF Mixed System
Const		F1= .400	F2= .600	F3=	F4=	JEP
Sep	444	.988	.980			.983
Oct	110.1	.959	.972			.967
Nov	39.07	.673	.758			.724
Dec	25.89	.479	.538			.514
Jan	25.51	.472	.530			.507
Feb	31.11	.568	.643			.613
Mar	35.03	.623	.706			.673
Apr	56.29	.816	.887			.859
May	126.0	.971	.976			.974
Jun	615	.988	.980			.983
Sum		7.537	7.970			7.797

[3:177]

Table 24. TABLE B SOLAR SAVINGS FRACTION AND AUXILIARY ENERGY

Location Dodge City, KS System DG+WW, R4

BLC $\boxed{7420}$ Btu/DD

DDns $\boxed{4960}$ F day

LCR $\boxed{19.03}$ Btu/DD sq ft

Col.	(1)	(2)	(3)	(4)	(5)
	From Table A Col. (9) or W1	From Appendix A or W2	(1) ÷ (2)	From Figs F-1 to 6, Equations W3, or W4	[1-(4)] x (2) x BLC
	S	DDs	S/DDs	"Monthly SSF"	Qauxs
Mon	Btu/mon sq ft	DD/mon	Btu/mon ft² DD		10^6 Btu/mon
Sep	24453	55.1	444	.983	.007
Oct	29904	271.7	110.1	.967	.067
Nov	27097	693.5	39.07	.724	1.420
Dec	26102	1008.4	25.89	.514	3.633
Jan	27765	1088.4	25.51	.507	3.983
Feb	26742	859.6	31.11	.613	2.468
Mar	26846	766.4	35.03	.673	1.861
Apr	20787	369.3	56.29	.859	.387
May	16856	133.8	126.0	.974	.026
Jun	16300	26.5	615	.983	.003
				Total	13.855

8SP

Annual Auxiliary Heat

Yearly SSF

$$SSF = 1 - \frac{\Sigma Qauxs}{Qauxns}$$

$$= 1 - \frac{\Sigma(5)}{BLCxDDns}$$

$$= \boxed{62\ \%}$$

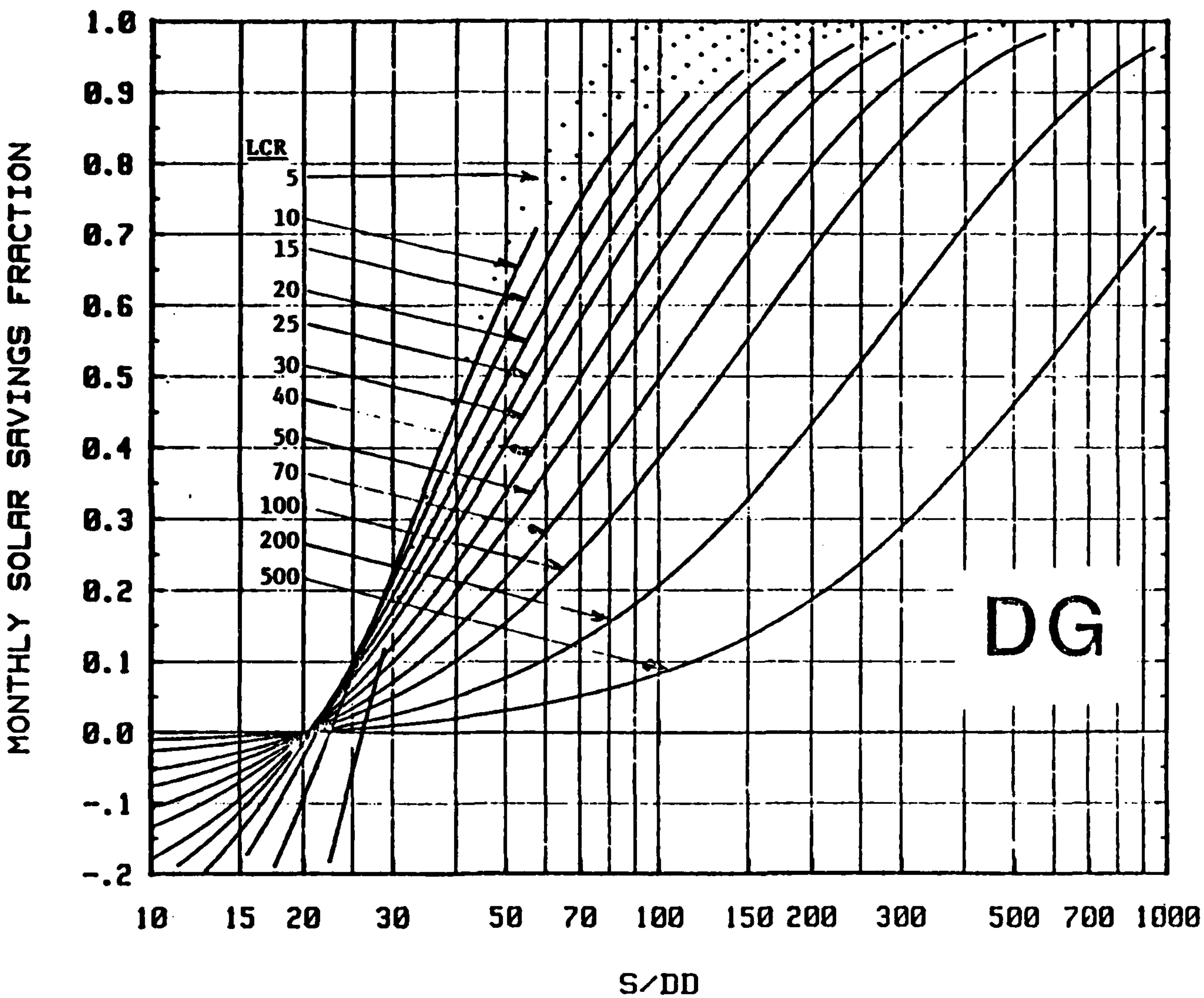

Fig. 8. Monthly performance curves for direct gain systems. [3:148]

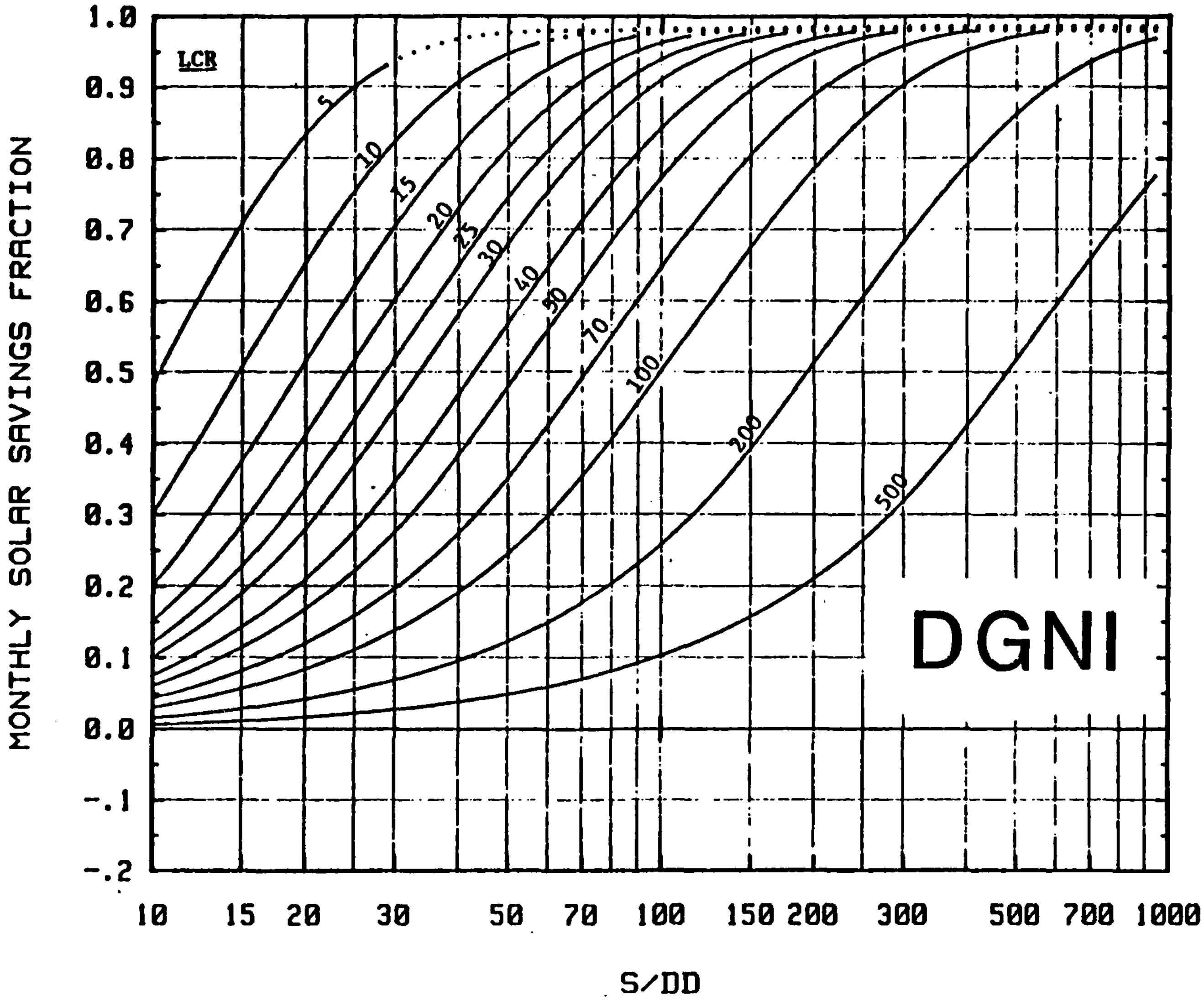

Fig. 9. Monthly performance curves for direct gain systems with R9 night insulation. [3:149]

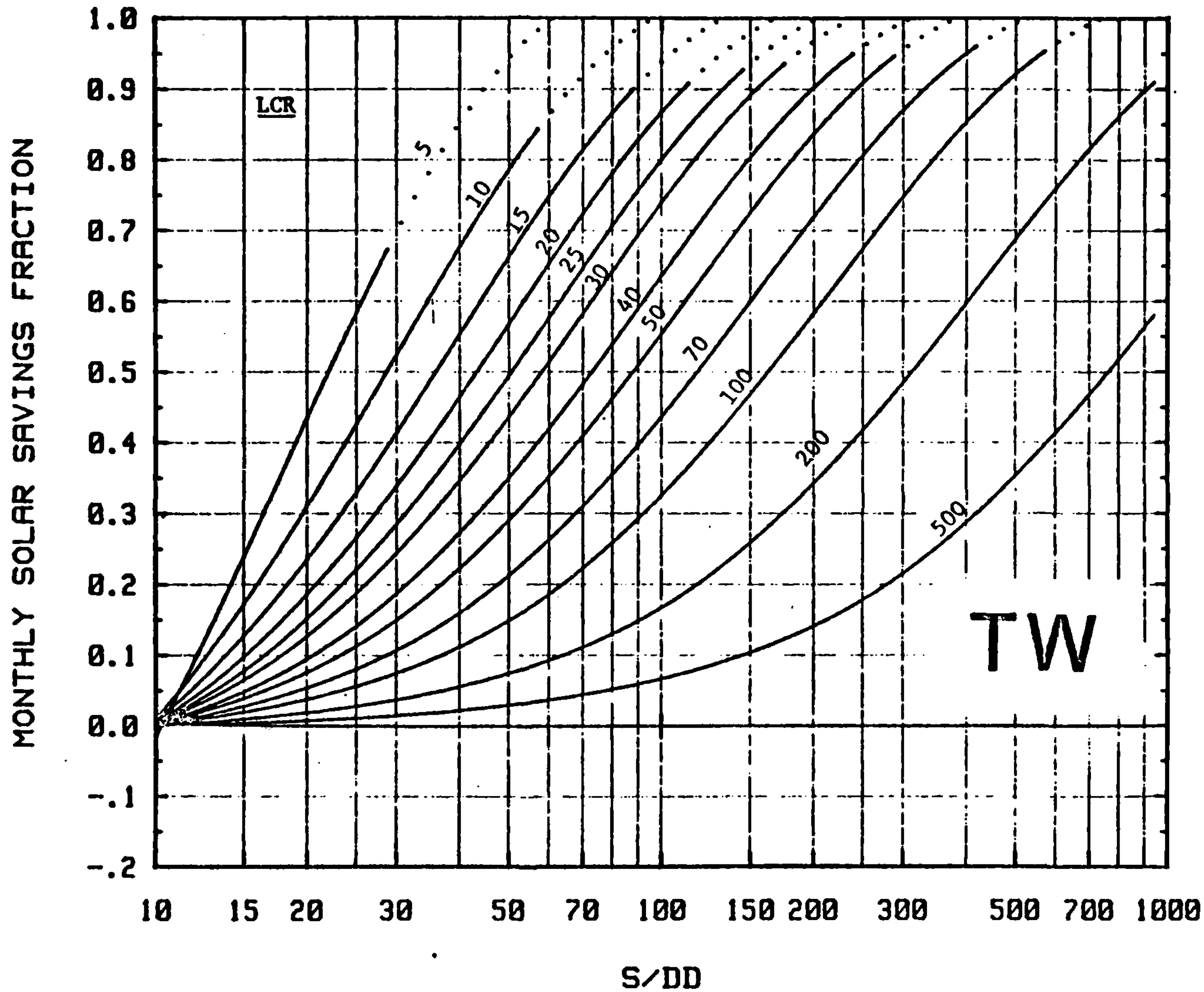

Fig. 10. Monthly performance curves for Trombe wall systems. [3:150]

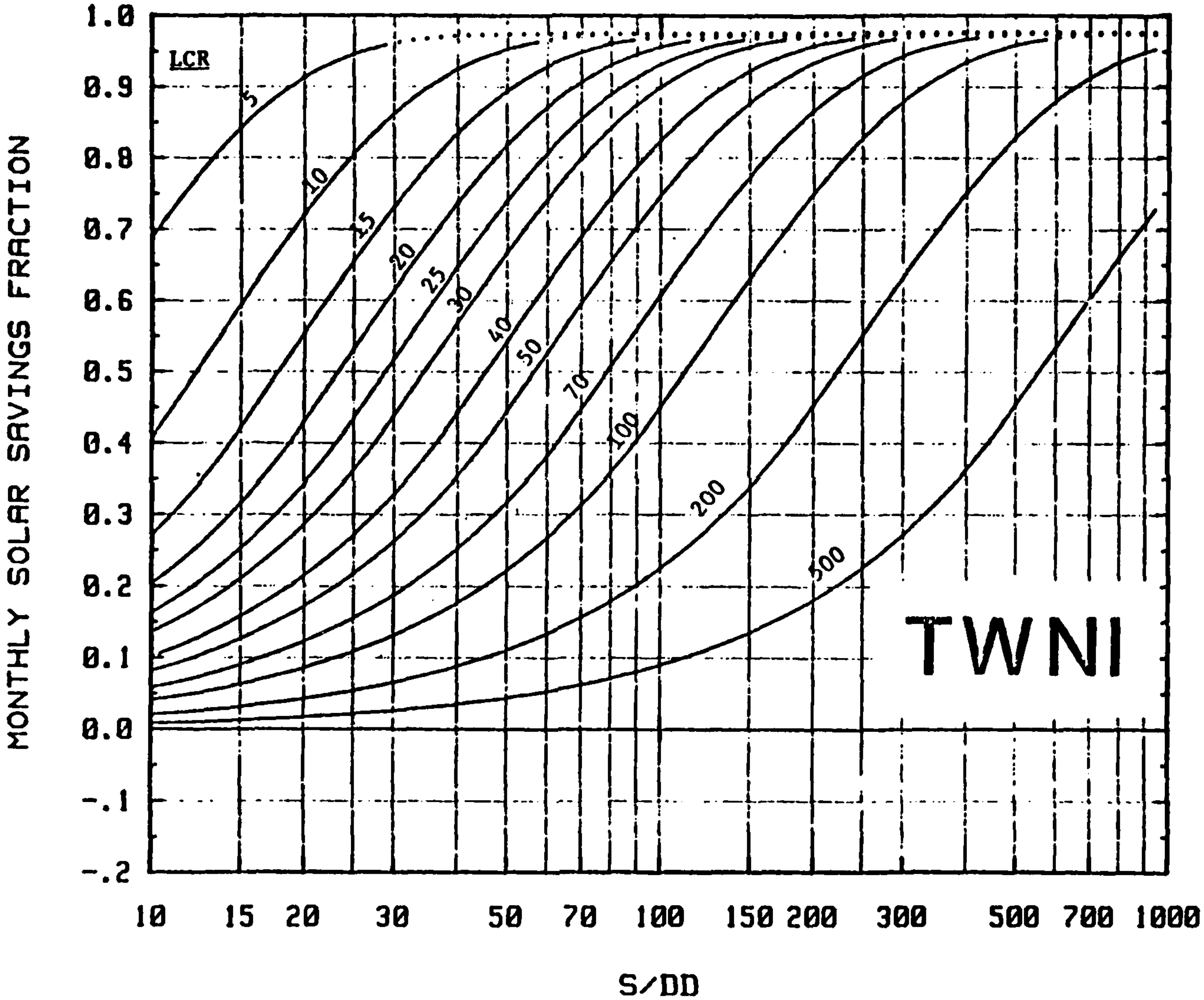

Fig. 11. Monthly performance curves for Trombe wall systems with R9 night insulation. [3:151]

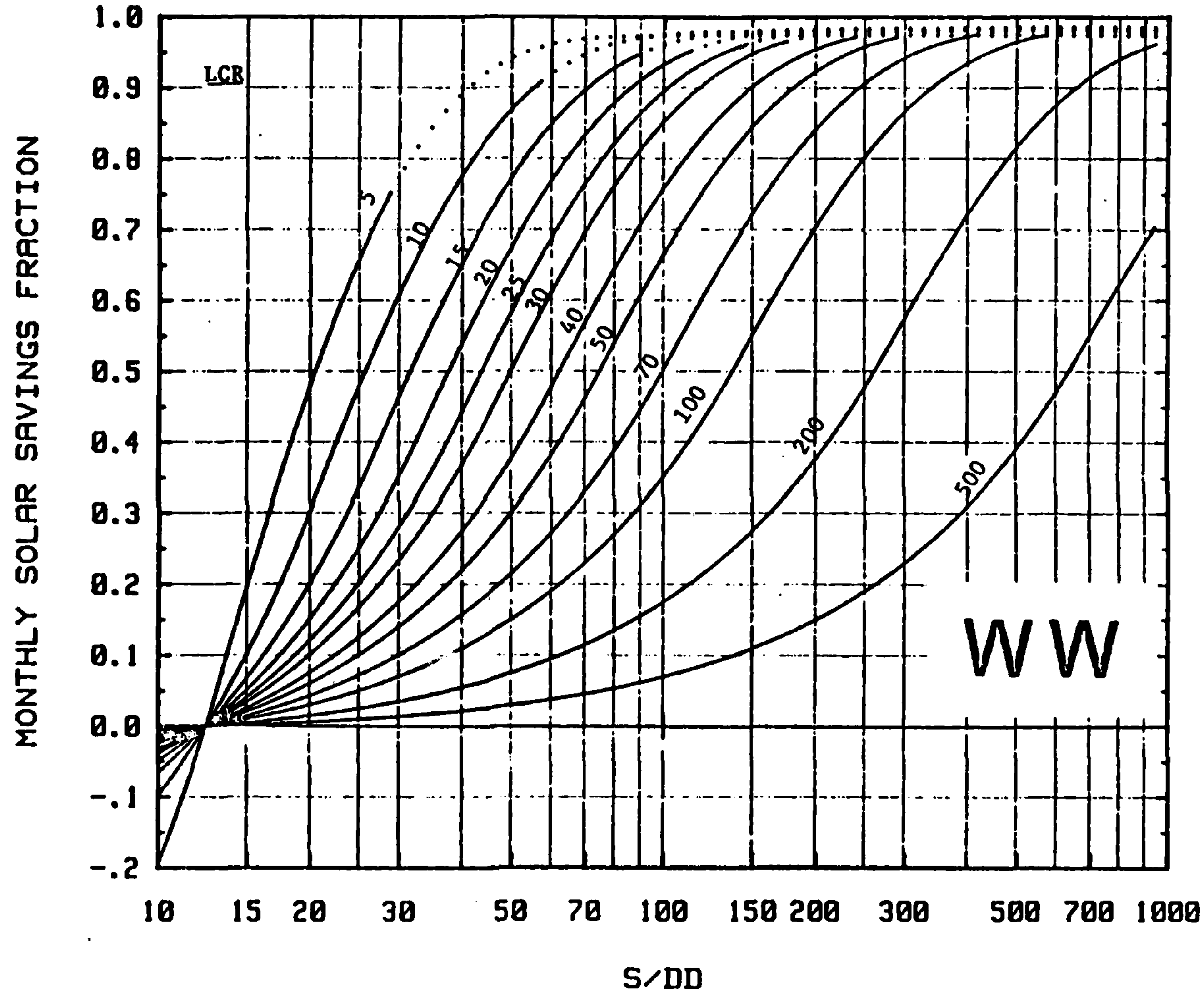

Fig. 12. Monthly performance curves for water wall systems. [3:152]

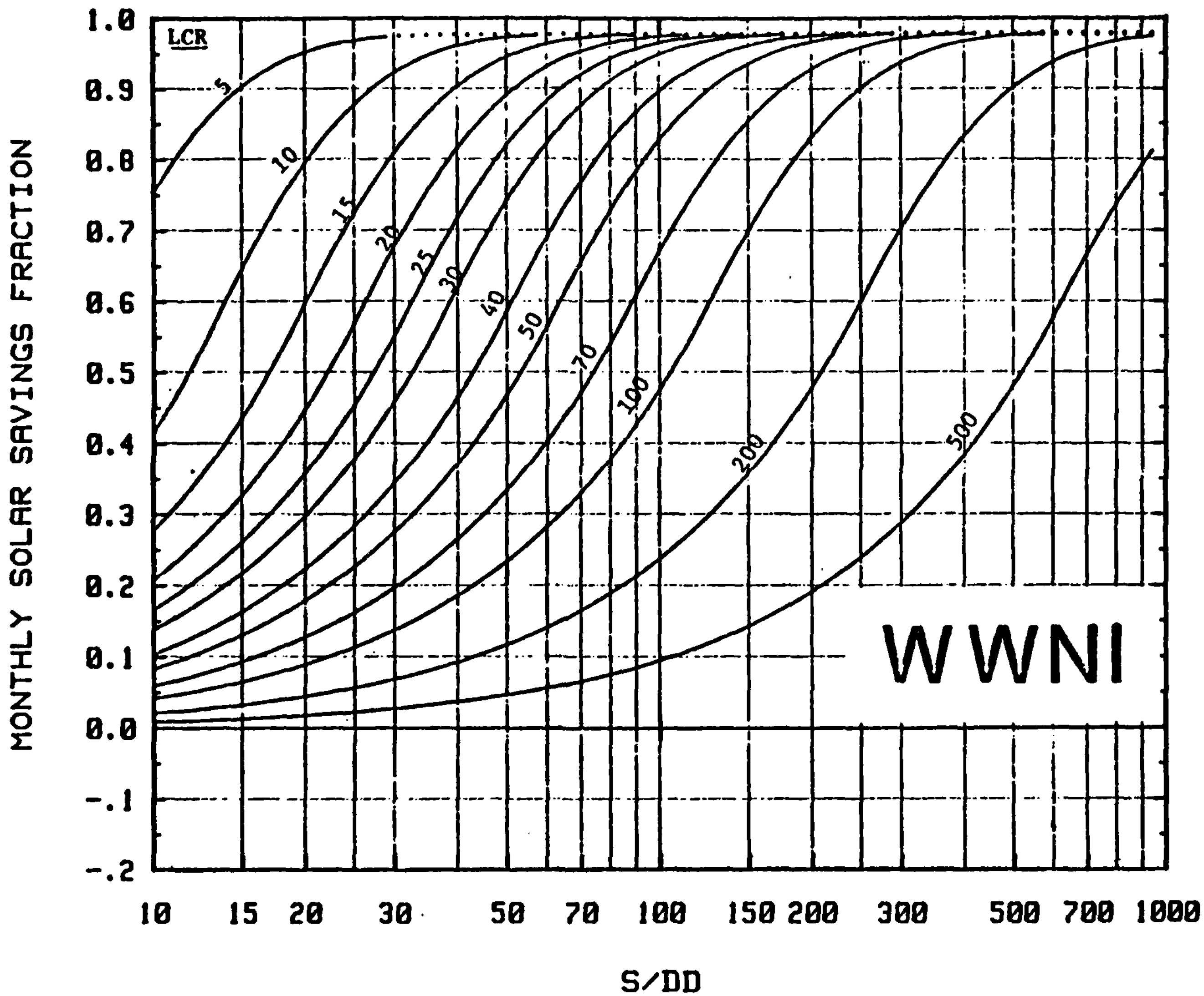

Fig. 13. Monthly performance curves for water wall systems with R9 night insulation. [3:153]

when the base temperature setting (Tbs) is not listed in Appendix A of the Handbook. Table "B" calculates the solar radiation per degree day (S/DD). This parameter is used to determine the SSF from the graphs. For "mixed" systems, worksheet "W4" can be used. Worksheet "W3" is useful when night insulation other than R9 is used.

Next, the temperature fluctuation or swing is calculated. The Handbook has developed this seven step procedure only for direct gain systems. The building is broken up into independent sections. Figure 14 is an example of the breakdown for a house utilizing extensive south glazing and a clerestory window for the northside hallway and bathroom. The storage mass is adobe brick. A worksheet is used for each type of surface. For the example, four worksheets were used, one each for the adobe mass walls, the frame walls, the ceiling, and the floor (which is part concrete and part brick). Table 25 is the worksheet, while Table 26 shows the same worksheet filled out for the example. The worksheet is useful in breaking down the surfaces into four classes as outlined in Table 27. Table 28 gives the Diurnal Heat Capacity (dhc) in Btu/ft^2 F. The Diurnal Heat Capacity for the entire surface (DHC) is obtained by multiplying the modified area from Table 26 with the dhc for the respective surface.

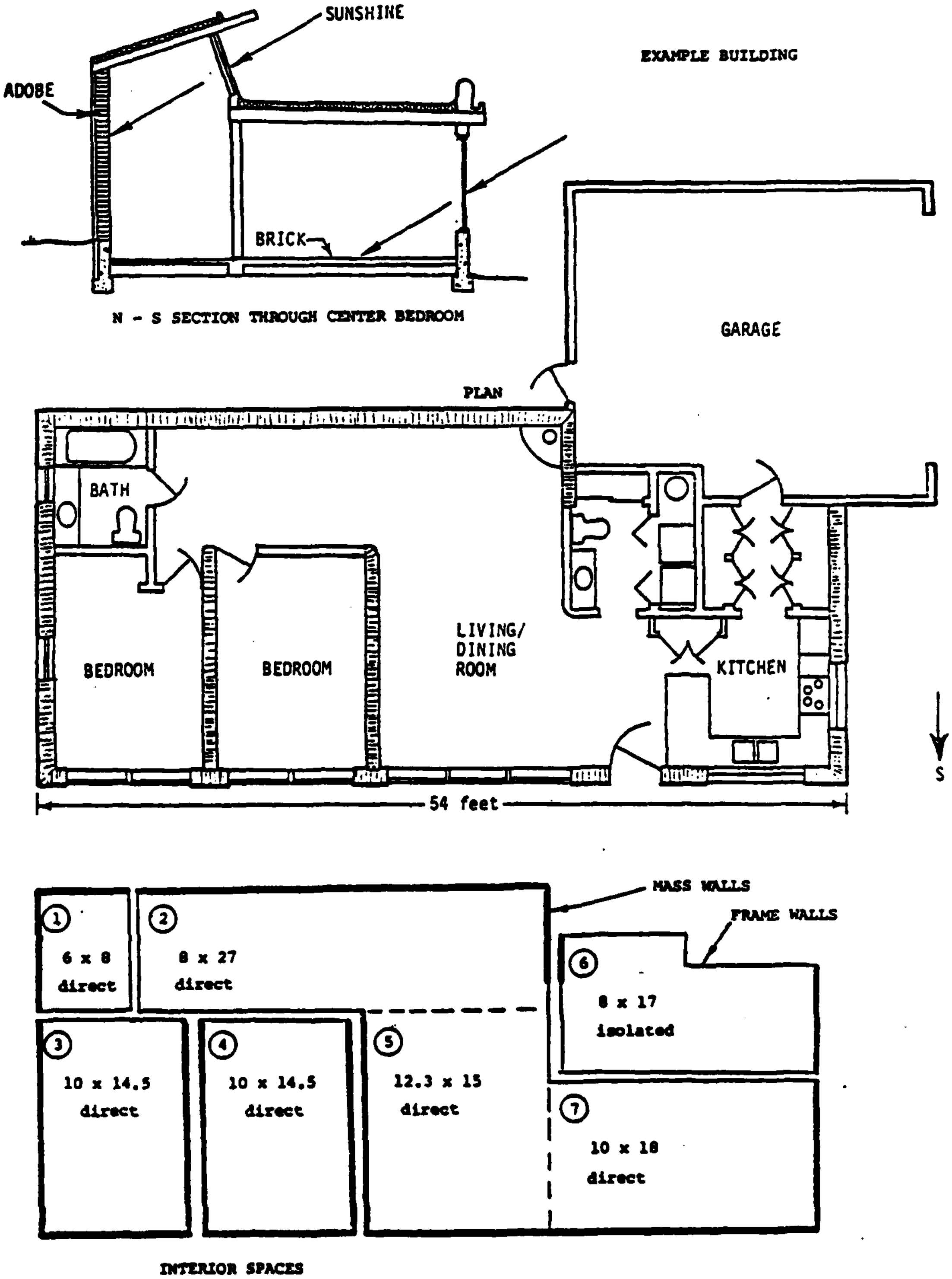

Fig. 14. Building used as an example for Diurnal Heat Capacity calculation. [3:187]

Table 25

DHC Worksheet

WORKSHEET

Surface type: ____________________

Area, in square feet

SPACE	GROSS	NET	Class 4	Class 3	Class 2	Class 1	α	f	$(\text{Class } 1) \times (1+\alpha f)$

[3:191]

Table 26

EXAMPLE OF FILLED-IN WORKSHEETS

WORKSHEET — Surface type: MASS WALLS

Area, in square feet

SPACE	GROSS	NET	Class 4	Class 3	Class 2	Class 1	α	f	(Class 1)x(1+αf)
1	182	178	78		76	24	.8	.6	35
2	429	429	86		243	100	.8	.8	164
3	359	305	72		81	152	.8	.5	213
4	359	311	72		87	152	.7	.5	213
5	251	179	50		53	76	.8	.5	106
6	92	92	92						
7	257	215	111		84	20	.8	.5	28
TOTALS	1929	1709	561		624	524			759

WORKSHEET — Surface type: FRAME WALLS

Area, in square feet

SPACE	GROSS	NET	Class 4	Class 3	Class 2	Class 1	α	f	(Class 1)x(1+αf)
1	182	167	36		131				
2	325	240	65		175				
3	92	80	18		62				
4	92	80	18		62				
5	46	46	9		37				
6	369	369	369						
7	166	139	79		60				
TOTALS	1271	1120	593		527				

WORKSHEET — Surface type: CEILING

Area, in square feet

SPACE	GROSS	NET	Class 4	Class 3	Class 2	Class 1	α	f	(Class 1)x(1+αf)
1	48	72			72				
2	216	324			324				
3	145	217			217				
4	145	217			217				
5	184	276			276				
6	136	136	136						
7	180	270			270				
TOTALS	1054	1512	136		1376				

WORKSHEET — Surface type: FLOOR

Area, in square feet

SPACE	GROSS	NET	Class 4	Class 3	Class 2	Class 1	α	f	(Class 1)x(1+αf)
1	B	48	24	24					
2	B	216	72	144					
3	C	145	72	23		50	.7	.5	67
4	C	145	72	23		50	.7	.5	67
5	B	184	61	41		82	.7	.6	116
6	B	136	136						
7	B	180	50			130	.7	.3	157
BRICK	B	764	343	209		212			273
CONCRETE	C	290	144	46		100			134

[3:188]

Table 27

DHC Class Classification

Location	Class
The surface of any massive material which receives some direct sun, except covered floor.	1
Covered floor (or any covered surface).	4
Walls which enclose a direct-gain room for which the solar gains exceed the room daytime losses.	2
All ceilings, except in sealed rooms (such as closets).	2
Walls which enclose other rooms which communicate by convection with direct gain rooms.	3
Uncovered floor in direct-gain rooms (not directly sunlit).	3
Floors other than in direct-gain rooms.	4
All surfaces in closed-off rooms	4

Table 28

DIURNAL HEAT CAPACITY*
(Btu/ft^2 F)

		Material					
		Concrete	Limestone Rock	Brick	Pine Wood	Dry Sand	Adobe
density (lb/ft^3)		143	153	112	31	95	120
specific heat (Btu/lb F)		0.21	0.22	0.22	0.67	0.19	0.20
thermal conductivity (Btu/ft F hr)		1.0	0.54	0.40	0.097	0.19	0.332
Class 1 & 2 (direct)	1"	2.50	2.80	2.05	1.71	1.50	2.00
	2"	4.99	5.52	4.04	2.96	2.90	3.92
	3"	7.37	7.81	5.73	3.14	3.86	5.44
Daily Heat Stored	4"	9.47	9.17	6.74	2.93	4.14	6.20
Surface ΔT	6"	11.94	9.30	6.86	2.76	3.82	6.05
	8"	12.14	8.63	6.36	2.77	3.62	5.62
	12"	10.99	8.29	6.10	2.77	3.61	5.49
	16"	10.65	8.33	6.13	2.77	3.62	5.52
Class 3 (indirect)	1"	2.28	2.48	1.91	1.58	1.43	1.86
	2"	3.63	3.71	3.10	2.26	2.39	3.00
	3"	4.21	4.05	3.54	2.21	2.70	3.39
Daily Heat Stored	4"	4.40	4.06	3.60	2.07	2.67	3.41
Room ΔT	6"	4.37	3.84	3.40	1.99	2.46	3.19
	8"	4.22	3.69	3.24	2.00	2.38	3.05
	12"	4.02	3.65	3.20	2.00	2.39	3.04
	16"	4.00	3.66	3.21	2.00	2.39	3.04

*The wall is assumed to be insulated on the back side, or to be back-to-back with another wall of the same thickness having the same surface boundary condition.

[3:182]

Lastly, an economic analysis is performed for the design. The Handbook considers three "principal elements".

- Investment for solar heating system
- Investment for energy conservation
- Recurring cost of auxiliary heating

The Handbook considers energy conservation as an important variable in the economic analysis. Energy conservation decreases the LCR causing an increase in the SSF.

The cost estimate for the passive system can become complex. The Handbook suggests dividing the system components into its functional area. Table 29 shows the functional elements. A cost estimate can be made on each item in Table 29. This estimate is aided by the costing worksheet in Table 30.

Care is needed when estimating the cost of the passive system. The estimate must be for costs that would not occur if the system was not used. If, for example, the wall would be 4 inches thick brick without a passive system and a 6 inch wall is desired because of the passive system, then the cost would be for 2 inches of brick. Also, the deletion of items must be deducted from the passive system cost. For example, the cost of a conventional wall must be subtracted from the cost of the glazing. Table 31 is a listing of items commonly replaced by the passive system.

The above description expands on the discussion about the Handbook in Chapter 3. However, it does not present

Table 29. Function Elements Breakdown

Collection	Storage	Distribution	Controls	Auxiliary Heating Equipment	Envelope
Glazing	Containment	Ducting	Overhang	Ducted Warm Air Heat Pump	Walls Ceiling
Framing	Material	Piping	Movable Insulation	Resistance Wire Furnace	
Absorption	Support	Vents & Dampers	Reflectors-Glare Control		Windows
Reflectors		Blowers, Pumps & Fans	Mechanical/Electrical Thermostats Timers Wiring	Hydronic Radiators Boiler	Doors
Support				Direct Zone Electric Resistance or Radiant Panels	Infiltration
			Ancillary Equipment	Combustion Stove Wood, Coal, Oil, Other Fireplace Window Unit	

[3:211]

Table 30. COSTING WORKSHEET (EXAMPLE)

Project Number: 16
Functional Element: COLLECTION
Sheet # 1 of 4
Design Description: TROMBE WALL
Date: 4/15/78
Location: ALBUQ. N.M.
Calculated by: SEYMOUR SUNSHINE

ITEM	DESCRIPTION	COST UNIT	COST				AMOUNT	TOTAL COST	NOTES
			MAT.	LABOR	O&P	TOTAL			
GLAZING	PATIO GLASS 76"x46" 5/8" TEMPERED DOUBLE	$/ft²	2.50	.15	.33	3.58	12 UNITS (292 ft²)	$1045.36	
FRAMING	ALUMINUM FRAMING	$/ft	3.00	.50	.35	3.85	180'	693.03	
ABSORB-TION	BLACK HEAT-RES. PAINT	$/ft²	.05	.15	.02	.22	350 ft²	77.00	
TOTAL								$1815.39	

[3:213]

Table 31

CONVENTIONAL CONSTRUCTION ITEMS COMMONLY REPLACED BY PASSIVE DESIGN ELEMENTS

FUNCTIONAL ELEMENT	PASSIVE SOLAR FEATURE	DISPLACED CONSTRUCTION FEATURES			
		STORAGE WALL	STORAGE ROOF	DIRECT GAIN	ATTACHED SUNSPACE
Collection	Glazing	Normal Wood Frame, Concrete, or Masonry Wall with Insulation	None	Normal Wood Frame, Concrete, or Masonry Wall with Insulation	None
	Framing		None		None
	Absorption		None		None
Storage	Containment Material		Roof Structure Replaced Interior & Exterior Walls Replaced with Load Bearing Walls	Conventional Slab on Grade if Augmented Interior walls replaced with mass	Adjoining Exterior Wall if made massive to provide storage
	Support	Normal Foundation	Normal Foundation	Normal Foundation	
Distribution	Ducting	None	None	None	None
	Vents & Dampers	None	None	None	None
	Blowers, Pumps, Fans	None	None	None	None
Controls	Overhang	Replaced Trim Drapes, etc.	None	Replaced Trim Drapes, etc.	None
	Movable Insulation		None		None
	Reflectors	None	None	None	None
	Mechanical/Electrical	None	None	None	None
Auxiliary	Changes in the auxiliary heating system may allow changes in the conventional distribution and control items in which case the extra costs or credits should be accounted for.				

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the complete procedure. For example, a sensitivity analysis is presented to show the effect of various parameters such as thermal storage mass, number of glazings, overhang, and ground reflection. Designing fan-forced rock beds is discussed. Also, appendices are included to further discuss monthly solar radiation, solar geometry and shading, solar radiation conversions, performance measures, generalized economic analysis techniques, and diurnal heat capacity.

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